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THE FORAMINIFERA

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THE FORAMINIFERA

AN INTRODUCTION TO THE STUDY OF THE PROTOZOA

BY

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TO

THOMAS RUPERT JONES

BY WHOSE LABOURS AND FRIENDLY SYMPATHIES

I HAVE BEEN GREATLY HELPED

PREFACE

THE classical volume of Dr. W. B. Carpenter, written in conjunction with Professors Kitchen Parker and Rupert Jones, is still an exceedingly valuable book for workers in this special branch of study, for it contains the pioneer work of those authors on the morphology and microscopic shell structure of Foraminifera.[1] The monographs of Drs. W. C. Williamson[2] and H. B. Brady[3] are also indispensable as works of reference. But these and others more recently published are voluminous and not always easily accessible to the student; whilst the increasingly large number of smaller works on the subject, written by Continental, English, and other authors, which have from time to time appeared in the various publications of Scientific Societies and in periodicals and journals, are quite outside the scope of the general student's reading.[4]

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[1] *Introduction to the Study of the Foraminifera.* Ray Society publication. London, 1862.

[2] *The Recent Foraminifera of Great Britain.* Ray Society's publication. London, 1858.

[3] *Report on the Foraminifera: H.M.S. 'Challenger,' Zoology,* vol. ix. 1884.

[4] For the literature on Foraminifera to 1888 consult C. D. Sherborn's *Bibliography of the Foraminifera,* London, 1888, and the supplemental work, to 1898, by Paul Tutkowski, Cracow, 1898.

Of late years also much attention has been directed to the elucidation of the life history of the Foraminifera and other groups of the Protozoa, whilst fresh discoveries concerning the geographical distribution of the fossil Foraminifera and their range in time have served to make our knowledge of this group more complete, and in some cases have disturbed the generally accepted ideas about the early, if not the actual primæval, forms of these persistent types of animal life.

With a view, therefore, of meeting a demand which has arisen for a concise account of the Foraminifera, suited to the requirements of the student of Natural History and Palæontology, the following pages have been written.

For friendly criticism of the earlier chapters of this book, and for valuable advice, I am much indebted to Professor G. B. Howes, LL.D., F.R.S. I also take this as a fitting opportunity for expressing my thanks to Professor J. W. Judd, C.B., LL.D., F.R.S., for the facilities granted from time to time, in the laboratory of the Royal College of Science, for working out and recording observations on various deposits, fossil and recent, without which some sections of this book would have been incomplete.

F. CHAPMAN.

January 1902.

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THE FORAMINIFERA

CHAPTER I

INTRODUCTORY REMARKS ON THE NATURE AND OCCURRENCE OF FORAMINIFERA—IMPORTANCE OF THEIR STUDY TO THE ZOOLOGIST AND GEOLOGIST—THE STRUCTURE AND CLASSIFICATION OF THE PROTOZOA—THE POSITION OF THE FORAMINIFERA IN THE PHYLUM PROTOZOA.

Where to find Living Foraminifera.—The most casual observer who takes a walk by the seashore, especially if it be in a sheltered bay with a gently sloping strand, will have noticed the sandy streaks left by the receding tide. If this sand, which to the eye appears like a collection of mere chalky and sooty fragments, be examined with a pocket lens, some of the whitish specks will be seen to be tiny but perfect shells. These delicate little shells belong to the lowest group or phylum of animal life, and they are known as Foraminifera, 'hole-bearers,' as the name implies, on account of their internal septa having perforations.

There may be other little organisms accompanying the Foraminifera in this sand, such as the shells or carapaces of bivalved crustaceans or Ostracoda, the young shells or fry of molluscs, or even seeds of plants. The shells of the Foraminifera are easily distinguished by their particular shape and texture: they are sometimes white and opaque, glassy or translucent, and often decorated with the finest and most beautiful surface tracery. Their minuteness, especially those in shore-sands, may be conceived from the fact that one observer, Plancus, counted 6000 in an ounce of sand from the Adriatic. This number is perhaps rather within than beyond the mark.

One of our best examples of a strand composed almost entirely of foraminiferal shells in the British Islands is that of Dog's Bay, near Connemara. The sand from this locality contains a very small admixture of molluscan shells, Ostracoda, and other marine organisms, and the lighter foraminiferous shell material is blown inland for a considerable distance, forming drifts and mounds. Messrs. Balkwill and Millett drew attention to this rich deposit some years ago, describing many species, since when Mr. Joseph Wright of Belfast has considerably added to the list, and the number now recorded from this bay alone amounts to 124 species and varieties. Through the courtesy of Mr. E. Welch the writer has been able to include a view of this bay, which is thus of so much interest to naturalists. (See Frontispiece.)

Fig. 1 represents a sample of shore-sand from the Sussex coast, containing numerous Foraminifera, associated with broken molluscan shells, fragments of corallines, Ostracoda, and quartz-grains.

The shells of Foraminifera collected from shore-sands, however, may not contain the living animal, since they have probably drifted and floated on the tide for some length of time.

The shallow-water sands of the Grecian Archipelago and the Levant often contain a large proportion of foraminiferal shells; and by taking a common washing sponge, obtained from such a locality, in the dry state before it has been used, and shaking it over a sheet of paper, we may obtain a quantity of fine sand which, on examination with a lens or low-power microscope, will often reveal countless shells of the Foraminifera (fig. 2).

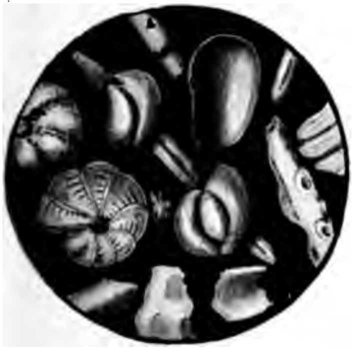

FIG. 1.—FORAMINIFERAL SAND FROM TIDE-MARKS ON THE SHORE AT LITTLEHAMPTON, SUSSEX. × 26. *Original.*

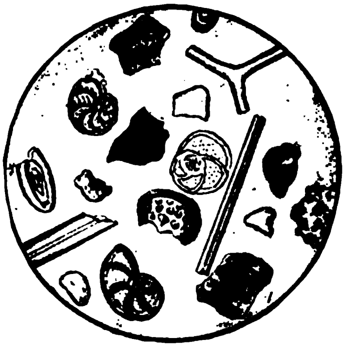

FIG. 2.—SAND FROM A COMMON SPONGE, CONSISTING OF FORAMINIFERA, SPONGE SPICULES, OSTRACODA, SHELL FRAGMENTS, AND SAND GRAINS. × 26. *Original.*

In order to see these tiny creatures alive let us take some fresh seaweed at low tide and place it in a glass jar of sea-water. After a short space of time the Foraminifera will be seen moving over the inside of the vessel, whither they have travelled from the seaweed, and they can then be observed with a moderately powerful lens.

Living Foraminifera are very beautiful objects when viewed by means of a back-ground illumination, using an objective of about 40 diameters. The shell under these conditions appears surrounded by a sort of cobweb of extremely fine sarcode threads, which, if observed closely, will be seen to exhibit a streaming movement, owing to the rapid circulation of crystalline particles in the sarcode, reminding one of the cyclosis or circulatory movements seen in the cells of certain plants. A reproduction of Schultze's figure of a living *Haplophragmium*, given above, affords a good idea of the appearance of the living organism (fig. 3).

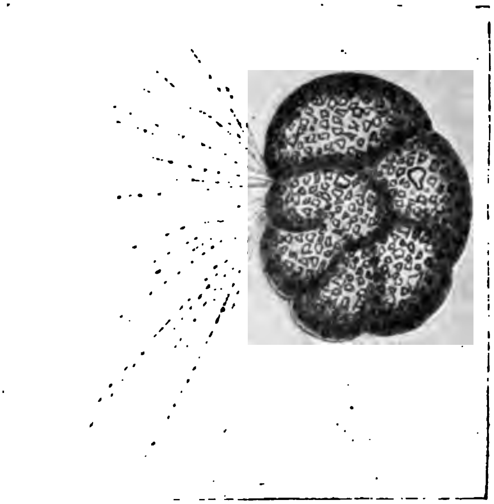

FIG. 3.—HAPLOPHRAGMIUM [NONIONINA SILICEA] WITH EXTENDED PSEUDOPODIA. × 72. *After Schultze.*

How to find Fossil Foraminifera.—Fossil specimens may also be obtained with very little difficulty;

as, for example, by crushing a piece of soft white chalk under water, and repeatedly washing the residue, taking care that nothing but the fine milky fluid is thrown away during the process of levigation. After drying the residue, the powder thus obtained will probably yield numerous specimens of Foraminifera. That some chalks and limestones are largely composed of foraminiferal shells we may see by examining

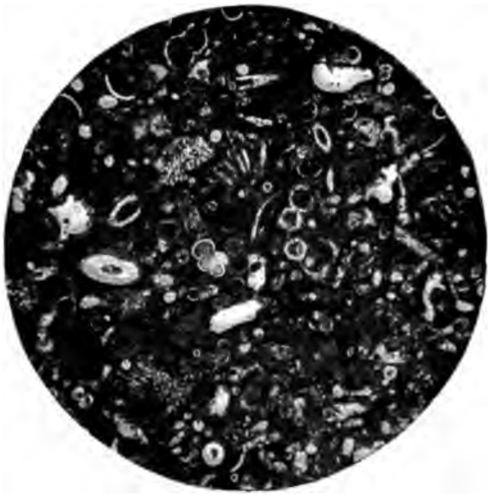

FIG. 4.—FROM A PHOTOMICROGRAPH OF A THIN SECTION OF CHALK FROM MISSENDEN, BUCKINGHAMSHIRE. × 36. *Original.*

thin slices of these rocks from certain horizons. Fig. 4 is taken from a photomicrograph of a section of the chalk-rock of Buckinghamshire; in this zone the Foraminifera are always abundant. The separated microzoa often contain some handsome forms, as the next illustration (fig. 5) will show. To be successful, however, in extracting Foraminifera from the chalk, it must be borne in mind that some strata are almost devoid of these organisms, and a little geological knowledge is requisite to secure a suitable piece from the proper horizon in the chalk series.

The majority of the Foraminifera are of marine habit, although many such species are capable of living far up the estuaries of rivers, provided the water is brackish and well within the reach of tidal influence; but under these conditions they are as a rule thin-shelled, chitinous, or dwarfed modifications of the more robust marine types. A few forms also are exclusively of fresh-water habit.

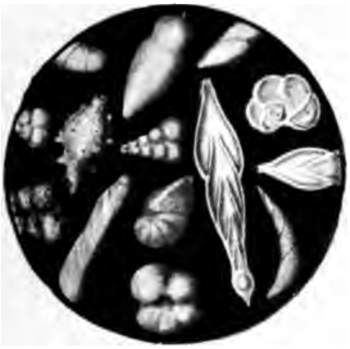

FIG. 5.—FORAMINIFERA WASHED FROM CHALK-ROCK NEAR DUNSTABLE. × 36. *Original.*

The shells of Foraminifera are usually microscopic, averaging from about $\frac{1}{25}$ inch down to $\frac{1}{100}$ inch (1 to ·25 mm.), but there are certain genera which attain a comparatively large size, such as *Orbitolites*, which sometimes reaches a diameter of $\frac{7}{10}$ inch (1·75 cm.); *Nummulites*, with a diameter of 4½ inches (over 11 cm.), and *Cycloclypeus*, 2¼ inches (5·7 cm.) There are also other genera, such as *Carpenteria* and *Polytrema*, which by their accumulative and encrusting growth form large masses of shell material, often reaching 5 inches in lateral expanse and an inch and a half to two inches in thickness.

The Foraminifera present many features of interest from a zoological point of view, for they exhibit in certain of their families so complex a shell structure that it seems quite marvellous that the perfect details of their investment have been produced by so lowly a type of animal life, in itself apparently so structureless. The great variability of the numerous types and so-called species of the Foraminifera, and the inter-relation of genera which at first sight are apparently distinct, lend additional interest to the study of the group.

Apart from their zoological interest, however, the remains of Foraminifera found in the various fossiliferous strata of the earth's crust are often of great importance to the stratigraphical geologist, since they assist in determining the age of a deposit, in many cases helping to clear up doubtful points regarding the conditions under which a particular bed was laid down. It must not, however, be inferred that species or types of Foraminifera are always distinctive of special geological horizons, for some well-marked forms are persistent (with some slight modifications in their shell structure) throughout nearly all formations from early palæozoic times to the present day. But when we study a facies or assemblage of these fossils from any given horizon we find it presents certain peculiarities which distinguish it from that found in another set of strata of a different age. A change in the aspect of a foraminiferal facies may also point to a change of condition under which the animals lived rather than to any great difference in age, and in such case the earlier aspect of the fauna would return at a later period, provided there did not elapse too great a space of time, when the former marine conditions recurred.

The Foraminifera have in past geological times been among the most active agents in building up the sedimentary rock masses of the earth, by secreting the carbonate of lime from the waters of the ocean.

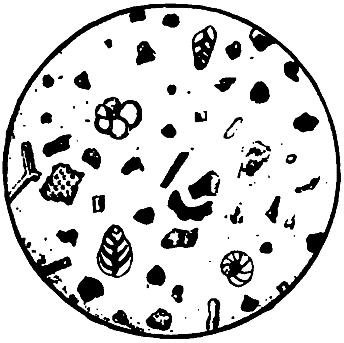

FIG. 6.—TERRIGENOUS (GREEN) MUD, WITH FORAMINIFERA. × 24. Off Cape Verde, 284 fathoms. *Original.*

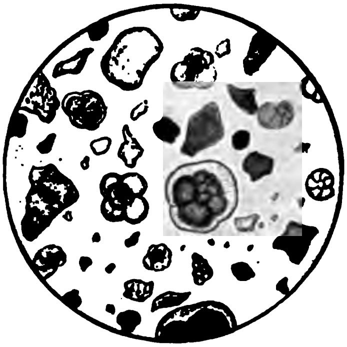

FIG. 7.—GLOBIGERINA OOZE. × 24. North Atlantic, 2,760 fathoms. *Original.*

This work is still being carried on by them around the shores of continents, where their accumulated shells go to form, along with the land *débris*, the terrigenous deposits (fig. 6), and over large areas of the ocean floor, where, intermixed with coccoliths, they form the well-known Globigerina ooze (fig. 7).

The organic rocks formed by the agency of Foraminifera are often of very great thickness and extent, and foraminiferal rocks are found interstratified with other deposits in almost every geological formation.

It is therefore essential that the stratigraphical geologist, in studying the sedimentary rocks, should become acquainted with the principal types of Foraminifera likely to be met with in this way.

THE STRUCTURE AND CLASSIFICATION OF THE PROTOZOA.

The Protozoa, of which the Foraminifera constitute an important group, are characterised by their simplicity of structure as compared with the higher animal groups, the metazoa. In this respect they correspond with the similarly elementary forms of vegetable life sometimes called the protophyta; and indeed it is difficult, if not impossible in some cases, to assign them to either the animals or the plants.

The protozoa are typically unicellular—that is to say, they often consist of a single animal cell which, with its nucleus, is complete in itself for the functions of life and growth. Any increase which takes place is made on the same general plan as the previous cell—that is, without any special differentiation of its structure, such as the formation of tissue, for any particular function. The protozoa consist of a jelly-like substance having a colloidal consistency, called sarcode. The sarcode has the ability to throw out extensions from the main mass, either of blunt processes or of fine hairlike extensions. The sarcode body may be naked or having a covering which in some cases is of extreme tenuity; in others there may be a denser covering or cortical layer, derived from the same sarcode body. These inner and outer portions may be termed respectively the endoplasm and exoplasm.

A good example of the protozoa may be seen in the amœba, which is common in pond water (fig. 8).

Protozoa may, at one time of their existence, form a coherent group or colony of cells. This, however, is merely a case of cohesion or aggregation after the increase of the original cell.

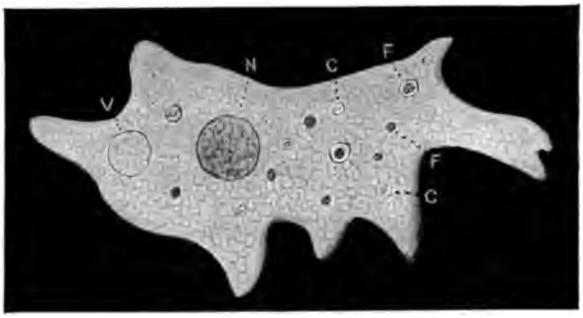

FIG. 8.—AMŒBA PROTEUS. × 500. *Original.*
N = nucleus, V = vacuole, F = food particles, C = crystalline bodies.

With regard to the phenomena and ordinary structures observed in protozoa we may notice the following as of most importance:—

THE NUCLEUS.—This is a small more or less solid body present in nearly all protozoan cells, having a granular structure, and sometimes containing smaller bodies of a like nature (nucleoli). It is capable of being stained with various reagents, such as picrocarmine, hæmatoxylin, or methylene blue. For the reproduction or division of the organism the presence of a nucleus seems essential (fig. 8, N).

FOOD PARTICLES.—Minute aggregates of solid particles, sometimes showing their organic and adventitious nature when they are incapable of being completely digested (fig. 8, F).

GLOBULAR BODIES AND CONTRACTILE VESICLES.—The former are spherical spaces filled with an oily-looking liquid, often surrounded by an empty space (vacuole); they probably represent stages in the digestive process on organisms taken in as food. The liquid inclusion has been proved, in the case of certain protozoa, to be of an acid nature.

The latter are capable of undergoing contraction during the life of the organism (fig. 8, V).

CRYSTALLINE BODIES.—In certain of the protozoa, as amœba, granules of a crystalline form occur, which are refractive; they are thought to represent the final stage in the digestion of the food taken in by the organism before it is assimilated by the protoplasm (fig. 8, C).

The protozoa increase by fission or binary division and by the formation of zoöspores. The first stage in the process of subdivision is the division of the nucleus. This takes place either by the simple process of binary division (fig. 9) or by the more complex and beautiful process of karyokinesis (fig. 10), in which the nuclear body is invested with strands of chromatin threads, becoming elongate and constricted in hour-glass form, and finally separated into two distinct bodies, the surrounding cell-contents giving rise to independent organisms. This latter process, however, seems rare in the Foraminifera.

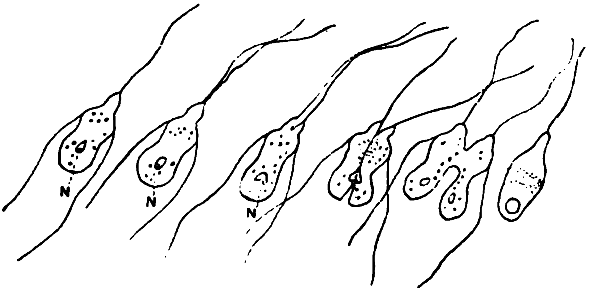

FIG. 9.—STAGES IN THE LONGITUDINAL FISSION OF A FLAGELLATE MONAD—DALLINGERIA DRYSDALI.
N = nucleus.

Protozoa are distinguished from the other and higher groups of animal organisms, sometimes collectively termed metazoa, by the absence of any structures resembling the organs and tissues of the higher

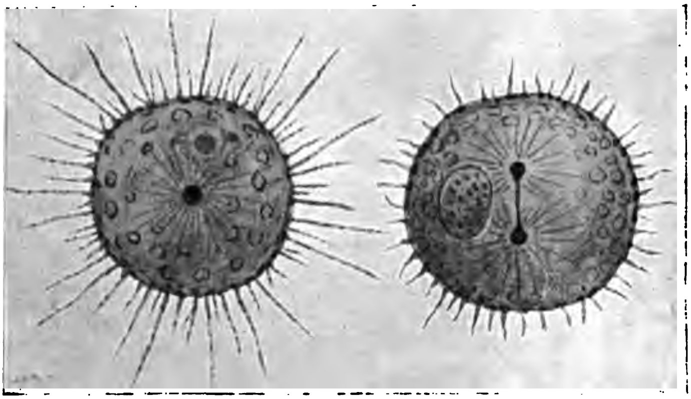

FIG. 10.—KARYOKINETIC DIVISION OF THE NUCLEUS IN ACANTHOCYSTIS.
After Schaudinn.

animals, which perform important functions for the benefit of the whole being. There is, moreover, no evidence of an organised nervous system, although something approaching a sense of touch may be possible.

Of the many classifications of the protozoa it will only be necessary to quote the two most generally accepted.

The first which is here given was drawn up by Professor Ray Lankester in 1891.

PROTOZOA.

GRADE A.—*Gymnomyxa*. (See fig. 11.)

Sections.	
Proteana . .	Class I.—PROTEOMYXA. Ex. *Vampyrella*, *Protomyxa*, *Archerina*.
Plasmodiata .	Class II.—MYCETOZOA. Ex. The *Eu-mycetozoa* of Zopf.
Lobosa . .	Class III.—LOBOSA. Ex. *Amœba*, *Arcella*, *Pelomyxa*.
Filosa . .	Class IV.—LABYRINTHULIDEA. Ex. *Labyrinthula*, *Chlamydomyxa*. Class V.—HELIOZOA. Ex. *Actinophrys*, *Raphidiophrys*, *Clathrulina*. Class VI.—RETICULARIA. Ex. *Gromia*, *Lituola*, *Astrorhiza*, *Globigerina*. Class VII.—RADIOLARIA. Ex. *Thalassicolla*, *Eucyrtidium*, *Acanthometra*.

GRADE B.—*Corticata*. (See fig. 12.)

Lipostoma .	Class I.—SPOROZOA. Ex. *Gregarina*, *Coccidium*.
Stomatophora	Class II.—FLAGELLATA. Ex. *Monas*, *Salpingœca*, *Euglena*, *Volvox*. Class III.—DINOFLAGELLATA. Ex. *Prorocentrum*, *Ceratium*. Class IV.—RHYNCHOFLAGELLATA. Ex. *Noctiluca*. Class V.—CILIATA. Ex. *Vorticella*, *Paramœcium*, *Stentor*. Class VI.—ACINETARIA. Ex. *Acineta*, *Dendrosoma*, *Podophrya*.

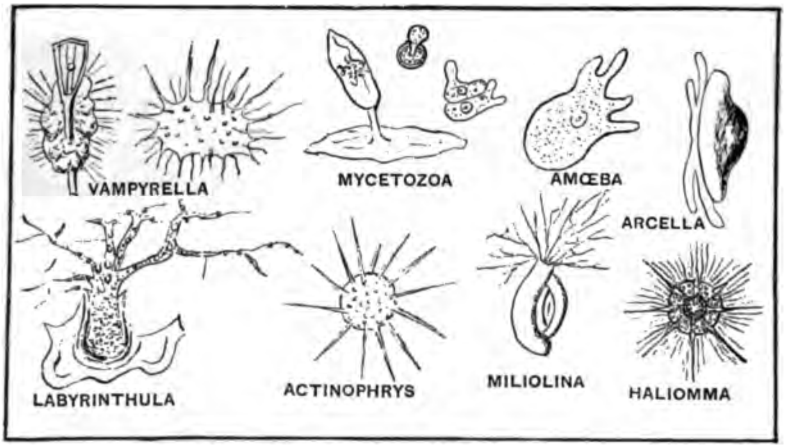

FIG. 11.—TYPES OF PROTOZOA—GYMNOMYXA.

The first division in this arrangement, Grade A, includes the Foraminifera, since the sarcode body of these animals is capable of free extrusion, as distinguished from those protozoa with a definite cortex or covering. Class VI. comprises the Reticularia, which are chiefly marine types; examples of the fresh-water types are *Gromia* and *Diaphoropodon.* This group takes its name from the fact that the prolongations of sarcode emitted by the organism form a *reticulum*

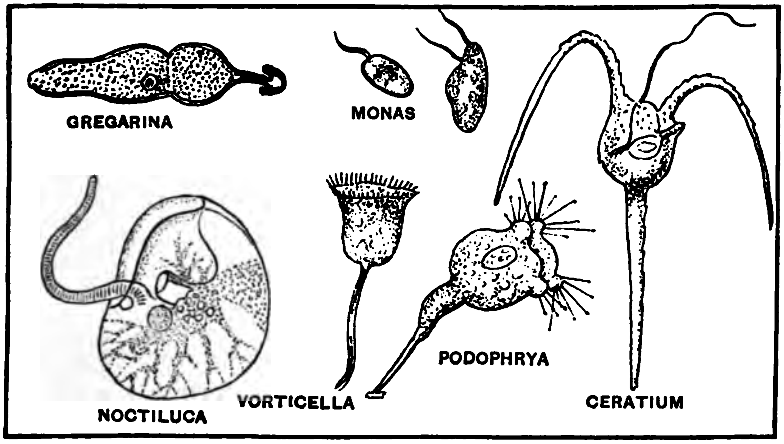

Fig. 12.—Types of Protozoa—Corticata.

of anastomosing threads. These sarcode extensions entrap minute organisms or other food particles, which are drawn to the mouth of the test, or may even enter it, there to be assimilated. This reticulated character of the extruded sarcode is very distinct from that of the true *Lobosa,* with which, however, they are grouped in another classification as Rhizopoda (Dujardin), and which have finger-like prolongations with rounded tips. These two groups are sometimes referred to as *Rhizopoda reticularia* and *Rhizopoda lobosa*.

The classification given by Parker and Haswell in their 'Textbook of Zoology'[1] is also a very convenient one. The divisions or classes are more comprehensive than in the previous table. Thus Class VI., the Reticularia (Foraminifera) of Ray Lankester, is included in the 1st group, the Rhizopoda, together with the Classes III., IV., V., and VII of that author.

PHYLUM PROTOZOA.

Class 1. RHIZOPODA.—Protozoa in which the amœboid form is predominant, the animal always forming pseudopods. Flagella are often present in the young, and occasionally in the adult. Encystation frequently occurs.

Class 2. MYCETOZOA.—Terrestrial protozoa in which the plasmodial phase is specially characteristic, as is also the formation of large and often complex cysts.

Class 3. MASTIGOPHORA.—Protozoa in which the flagellate form is predominant, although the amœboid and encysted conditions frequently occur.

Class 4. SPOROZOA.—Parasitic protozoa without organs of locomotion in the adult. Encystation is almost universal, and the young may be flagellate or amœboid.

Class 5. INFUSORIA.—Protozoa which are always ciliated, either throughout life or in the young condition.

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[1] *A Textbook of Zoology*, vol. i. pp. 43, 44. Macmillan, 1897.

CHAPTER II

THE CLASSIFICATION OF THE RHIZOPODA

THE name Rhizopoda was first used by Dujardin to designate that group of the Protozoa which have the ability of throwing out extensions of protoplasm called *pseudopodia*, which may be used either for prehension and locomotion or for the purpose of gathering minute organisms for food, whence they derive the name Rhizopoda (root-footed animals). This class of animal is characterised by its extreme simplicity of structure, and is represented in a general sense by the *amœboid* type. In strict signification, however, the *amœba* differs from the Foraminifera in having the pseudopodia finger-like or lobose (*Lobosa*; see fig. 8), whilst the Foraminifera have thread-like and anastomosing extrusions of sarcode (*Reticularia*). See fig. 3.

The Rhizopoda, according to Dujardin, constituted a family of the Infusoria, and his arrangement comprised eight genera, as follows:—

1, ARCELLA; 2, DIFFLUGIA; 3, TRINEMA; 4, EUGLYPHA; 5, GROMIA; 6, MILIOLA; 7, CRISTELLARIA; 8, VORTICIALIS.

This arrangement did not include many important forms, and gave distinction to others now known to be closely related.

Another scheme of the Rhizopoda was published by Claparède and Lachmann in 1858–9. They divided the group into four Orders—I. PROTEINA (including *Amœba* and *Actinophrys*); II. ECHINOCYSTIDA (*Radiolaria*); III. GROMIDÆ (*Gromia*); IV. FORAMINIFERA.

The arrangement published by Dr. Carpenter in 1862 is one even now followed, with certain modifications—I. LOBOSA; II. RADIOLARIA; III. RETICULOSA (afterwards altered by Carpenter to RETICULARIA).

It will be observed that the group of the RHIZOPODA in these systems of classification comprise almost the whole of Ray Lankester's division of the GYMNOMYXA.

The following in detail is one of the latest arrangements of the Rhizopoda, viz. that of Parker and Haswell in their 'Textbook of Zoology' (vol. i. p. 46):—

CLASS RHIZOPODA.

Order 1. LOBOSA.—Rhizopoda with short blunt pseudopods.

Order 2. LABYRINTHULIDEA.—Rhizopods having a network of fine pseudopods, in which corpuscles travel to and fro.

Order 3. FORAMINIFERA.—Shelled Rhizopoda with fine branched and anastomosing pseudopods.

Order 4. HELIOZOA.—Rhizopoda with fine stiff radiating pseudopods.

Order 5. RADIOLARIA.—Rhizopoda having a shell in the form of a perforated central capsule, and usually in addition a siliceous skeleton. The pseudopods are long and delicate.

CHAPTER III

THE STRUCTURE AND REPRODUCTION OF THE FORAMINIFERA (*Rhizopoda reticularia*)

Structure.—Foraminifera differ from the lobose rhizopods, such as *Amœba*, not only in the form of their sarcode prolongations or pseudopodia, but in having an investing shell or test composed of carbonate of lime, of cemented sand-grains, sponge spicules, and other adventitious particles, or of chitin. It is true that some of the lobose forms possess a covering, or lorica, but these are exceptional, and in the case of *Arcella* it is merely a scale-like chitinous shield. *Difflugia* also bears some resemblance to the monothalamous (single-chambered) forms of *Reophax*, but the former genus is essentially of fresh-water habit.

The body substance of Foraminifera consists of protoplasm or sarcode, generally transparent and nearly colourless, but sometimes of a pale brownish, pink, or violet tint. The animal is usually divided into more or less numerous segments, each of which is separated from the adjacent one by a septal shell-wall, and which are connected with one another by slender filaments of sarcode, called stolons, which pass through the foramina of the septum.

To gain an adequate idea of the appearance of the living organism we cannot do better than quote the admirable description of *Gromia* which Dr. Carpenter gives in his 'Introduction to the Study of the Foranimifera.'

'In the *Gromiæ*, some forms of which inhabit fresh water, whilst others are marine, the sarcode body, which is of essentially the same character with that of *Lieberkuehnia*, is enclosed in a yellowish brown membranous "test" of ovoidal shape, with a single round orifice of moderate size, through which the protoplasmic substance extends itself from the interior through the surrounding medium. When the animal is in a state of rest the whole of this is drawn within the test; and when its activity recommences single fine processes are first put forth, which move about in a groping manner until they find some surface to which they may attach themselves. When this attachment has taken place new sarcode flows into them, so that they speedily increase in size; and they then elongate themselves by sending out finer ramifying processes, which, in diverging from each other, come into contact with those proceeding from other stems, and, by mutual fusion, form a set of inosculations or connecting bridges between the different systems of ramifications, so that the whole becomes a complicated network extending to a distance of six or eight times the length of the body. This network continues to undergo incessant changes, new filaments being put forth in different directions, sometimes from its margin, sometimes from the midst of its ramifications, whilst others are retracted. Not unfrequently it happens that at a spot where two or more filaments meet and fuse together a lamina is formed by the expansion of the viscous protoplasm that flows towards this point; and from such an expansion a new set of thread-like processes is given off, as from the central body.'

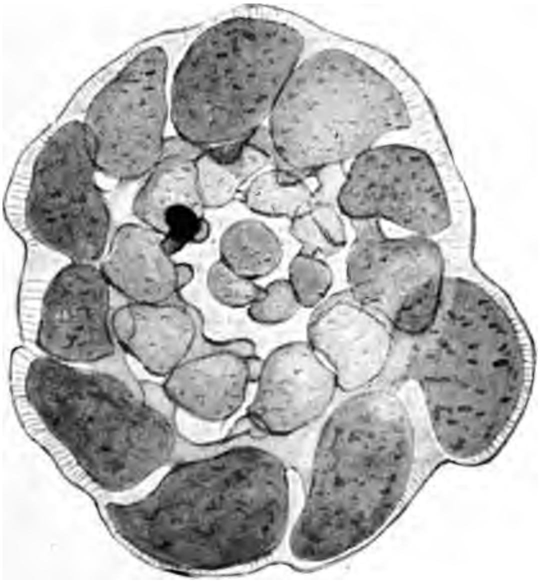

FIG. 13.—SARCODE BODY OF ROTALIA BECCARII, MEGALOSPHERIC FORM, WITH A NUCLEUS IN THE EIGHTH CHAMBER. × 170. *After Lister.*

As in the case of other protozoa the Foraminifera possess a nucleus, and sometimes contractile vacuoles (fig. 13).

For a long time, however, the presence of a nucleus in the Foraminifera remained undiscovered. It was in the genus *Gromia* that Dr. Wallich, the pioneer of deep-sea research, first observed it.

Since that time, however, this structure has been detected in nearly all genera which have been made the subject of careful observation. The following is a list of such genera, with the authorities: *Gromia* (Wallich, Max Schultze); *Spiroloculina* (Hertwig); *Miliolina* (Schulze); *Peneroplis* (Bütschli); *Orbitolites* (Bütschli, Lister); *Dendrophrya* (Möbius); *Saccammina* (Rhumbler); *Textularia* (Bütschli, Hertwig); *Lagena* (M. Schultze, F. E. Schulze, Grüber, Bütschli); *Globigerina* (Hertwig); *Spirillina* (Bütschli); *Discorbina* (Bütschli): *Truncatulina* (Lister); *Rotalia* (F. E. Schulze); *Calcarina* (Bütschli); *Polystomella* (F. E. Schulze, Lister, Verworn); *Amphistegina* (Bütschli); *Heterostegina* (Chapman); *Cycloclypeus* (Lister, Chapman).

The nucleus of the Foraminifera varies in size even in the same species. Lister's observations regarding the nucleus of *Polystomella crispa* show it to vary in its diameter from ·018 to ·066 mm. The nucleus often contains more or less numerous smaller bodies (nucleoli).

F. E. Schulze described the nucleus of *Polystomella striatopunctata*, and stated that it was a round body having, in some cases, a diameter of ·056 mm. and surrounded by a conspicuous membrane of considerable thickness; this latter appearance, however, seems to be exceptional, and Lister remarks that there is usually no perceptible investment of the nucleus other than the reticulum. Highly refracting nucleoli, lying in a clear and apparently fluid substance, occupied the interior. In quite young specimens only one nucleolus was found, but there were often as many as twenty or more in full-grown specimens. Schulze also noticed that the nucleus occupies a position in the middle third of the series of chambers, and often lies partly in one of the narrow canals connecting the chambers, being preserved in its progress from one chamber to another. The position of the nucleus is thus dependent on the number of chambers in the individual[1] (fig. 16).

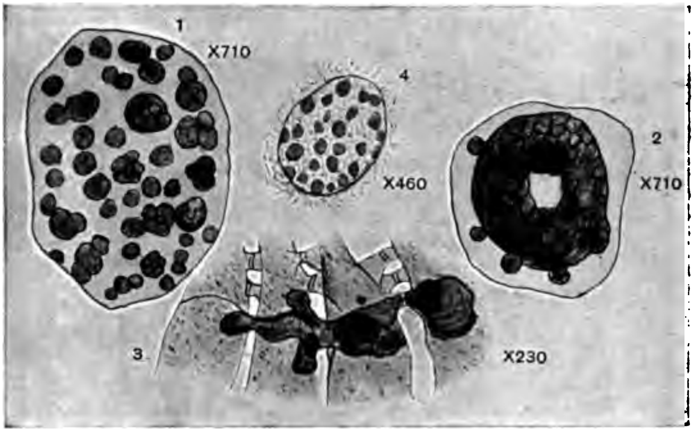

FIG. 14.

1. Nucleus of Polystomella crispa (L.), megalospheric form. 2. Nucleus with large vacuolated nucleolus, in P. crispa. 3. Nucleus of same species, which has lost its rounded form, lying within four segments. 4. Nucleus of a megalospheric specimen of Rotalia Beccarii. *After Lister.*

That the presence of a *nucleus* is essential for the *growth* and *reproduction* of the animal is proved by such observations as that of Verworn, who broke up a specimen of *Polystomella*, the larger pieces remaining alive, as shown by their extended pseudopodia, and only those fragments that possessed a nucleus were able to secrete fresh material to repair the broken shell. The outer surface of the nucleus, and even the nucleoli, are often covered with fine strands of chromatin forming a reticulum.

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[1] For further details of observations on the nucleus of the Foraminifera see Lister, *Phil. Trans. Roy. Soc.* vol. 186 B, 1895, pp. 401-453.

The nucleoli (fig. 14) appear to be the active portion of the nucleus in effecting the reproduction from an old nucleus by the formation of a morula-like centre within the nucleus. An interesting series of stages in the reproduction of nuclei in this way has been described by Schaudinn in *Calcituba polymorpha*, a Foraminifer from the Adriatic Sea (fig. 15). He shows that the nucleus, surrounded by protoplasm, is invaded by the latter, which breaks up into globules, penetrating little by little into the nucleus. The protoplasm disintegrates the chromatin

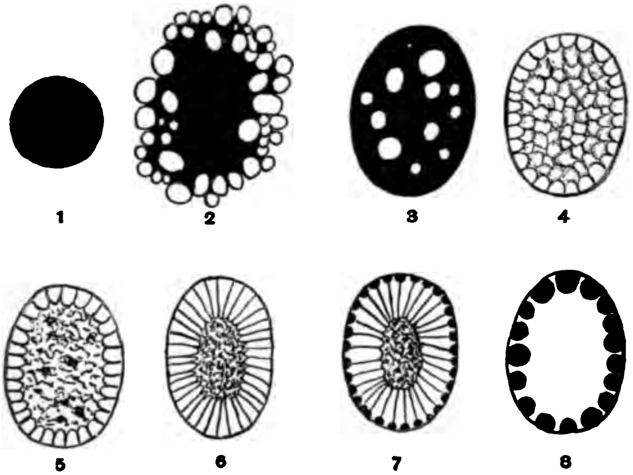


Fig. 15.—The Successive Stages in the Division of the Nucleus in Calcituba polymorpha. *After Schaudinn and Schlumberger.*

of the nucleus, rendering the mass granular. The external granules of the mass then arrange themselves against the nuclear membrane. The central portion of the nucleus then reunites and forms a solid body of chromatin. The result of this movement is to draw the peripheral granules towards the centre, and to lengthen them until they are attached by their points only to the external membrane. This results in the formation of little nuclei lining the inner surface of the membrane; when this membrane breaks up the nuclear bodies are disseminated through the surrounding protoplasm, and later play the part of nuclei.

The multiplication of the nucleus is, however, often carried out in the simple manner of binary subdivision; and a karyokinetic division has been observed by Lister in the nucleus of *Polystomella crispa.*

Solid particles of a more or less granular structure are often present in the protoplasm; they are capable of being stained like the nucleus by various reagents. They are referred to as nutritive particles, and probably represent various stages in the assimilation of food material.

Reproduction and Dimorphism.—The production of young in the shells of Foraminifera has long been known, for they were observed as long ago as 1847 by Gervais, who noticed a brood of young shells, each consisting of a single large chamber, and numbering about one hundred, grouped together in the orifice of a species of *Miliolina* which had been kept in sea water. Further, in 1856 Max Schultze noticed an example of the same genus which, after remaining on the side of a vessel containing sea water for from eight to fourteen days, produced about forty young individuals (fig. 16). Their shells consisted of a central chamber with a second chamber coiled partially round it. The condition of the parent shells after this process was such that Schultze concluded that the protoplasmic contents are used up in the formation of the young, for nothing but a little granular matter remained behind.

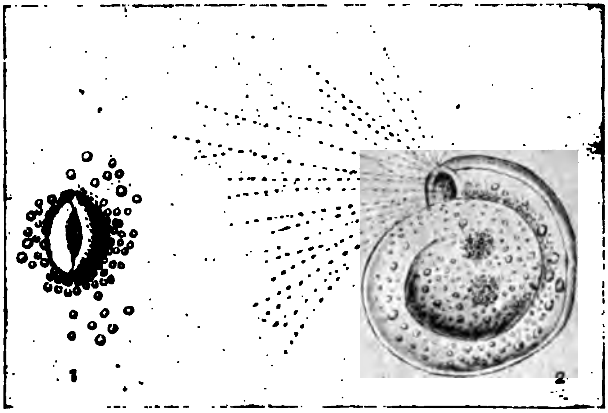


FIG. 16.

1. Miliolina from Trieste, surrounded with young. × 15. 2. A young specimen more highly magnified, showing extended pseudopodia. × 330. *After Schultze.*

Both Ehrenberg and Strethill Wright, a few years later, observed the tiny shells of young *Spirillinæ* living within the mouth of the individuals of advanced growth. This particular fact, indeed, suggested to

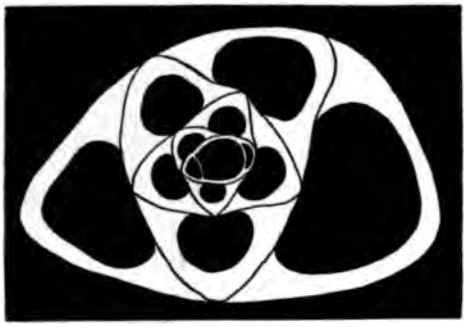
Ehrenberg the specific name for that form of *Spirillina*, namely, *S. vivipara.*

In his 'Introduction' Dr. Carpenter in 1862 mentions the fact that Professor Kitchen Parker had noticed young specimens having an investing shell occupying the peripheral chambers of *Orbitolites*; and soon after, another independent observer, Semper, noticed the same thing.

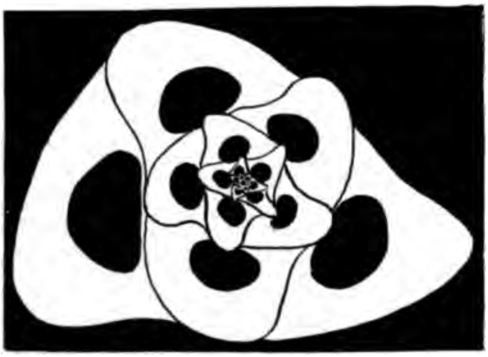
This leads us to another side of the same question, namely, the phenomenon of dimorphism; for all the specimens found in the peripheral chambers of *Orbitolites* have invariably a comparatively large primordial cell or chamber.

The dimorphism referred to consists in the same species exhibiting two distinct forms of shell. It was shown by Munier Chalmas in 1880 that Nummulites occurring in the same strata, and having the same external characters, fall into two groups; one possessing a large central chamber and a small disc, the other a small central chamber and a large disc. These are respectively termed form A and form B, or the megalospheric and microspheric stage of the species. This phenomenon is best seen in a half-section of the shell taken through the middle of the test, or in a thin median section (fig. 17).

Further observations on these two types of shell-form were made by De la Harpe on Nummulites, and in 1883 and 1885 by Schlumberger in collaboration with Munier Chalmas on dimorphism in the MILIOLIDÆ. These authors have shown that in this group the internal arrangement of the chambers is different for the two forms of one species. For example, in *Biloculin* *depressa* there are two forms—A, with a larg central chamber 200-400 μ[1] in diameter, and wit an outside diameter of the test of 2·1 mm.; and B



MILIOLINA (QUINQUELOCULINA) SEMINULUM.
Form A. × 100.



MILIOLINA (QUINQUELOCULINA) SEMINULUM.
Form B. × 90.

FIG. 17. *After Schlumberger.*

with a small central chamber 20 μ in diameter and an outside diameter varying from 1·5 mm. to 2·64 mm In form A of this species the arrangement of th chambers is biloculine from the commencement, but in form B the minute central chamber is followed by a series of chambers arranged in the quinqueloculine manner, the biloculine arrangement not being attained until the eleventh chamber is formed. Many other genera were described by these authors as having true dimorphic characters.

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[1] $\mu = \frac{1}{1000}$ millimetre.

In the case of *Orbitolites complanata*, which has been investigated by Brady and Lister, its dimorphism presents many points of interest. Form A is smaller than form B; and Lister found that in a large series of the former the number of rings of chamberlets is usually under thirty, whilst form B has from 79 to 110 rings. As the microspheric form increases in size the edge of the disc becomes double, so that a radial section at right angles to the plane of the disc is Y-shaped. The marginal chambers of this form (B) are not divided into small chamberlets, but consist of large chambers as high as the disc is thick. These brood-chambers, as they are called, contain the young forms, which in all cases are megalospheric. The megalospheric forms, on the other hand, often show numerous compact bodies of different sizes and irregular shape, derived by disintegration of the nucleus.

The megalospheric form is, as a rule, much more abundant than the microspheric. Of *Polystomella crispa* Lister gives the proportion which he found of forms A and B as 34 to 1. Of *Adelosina polygonia* Schlumberger gives the proportion as 8 to 1.

Of *Heterostegina depressa* the difference is still more marked, being as great as 300 to 1.

In the megalospheric form of *Polystomella crispa* Lister states that the breaking up of the nucleus gives rise to numerous small nuclear bodies, each of which afterwards becomes a centre of a flagellated zoöspore.

The general conclusion from the observations which have been made on dimorphism by some authors is that, rather than a sexual difference, the two forms represent alternate phases of generation; for the reason that both the megalospheric and microspheric tests can produce megalospheric young.

Some recent observations by Schaudinn[1] have thrown light on the hitherto obscure and curious phenomenon of fused tests often found in the Foraminifera, as in *Textularia folium*, *Patellina*, and *Discorbina*. This is due to the conjugation of two or more individuals, whose nuclei are in a state of rest, that is, not undergoing subdivision. Maupas had already pointed out that by long-continued fission the lower forms of life were liable to weakening and final extinction, but by fusion of the protoplasm and contents the organism undergoes rejuvenescence. The process of fission of the nucleus has been termed Karyogamy, and the process of fusion of the cytoplasts Plastogamy. Hartog defines Plastogamy as the cytoplastic union of cells without nuclear fusion. The plastogamic reproduction of *Discorbina* is shown by Schaudinn to occur as follows. The flat or inferior faces of the tests are brought together with the apertures coinciding. The walls of the last formed chambers are sometimes resorbed, and an enclosing shell made around the space between the tests. Then follows the breaking up of the nuclei, and the formation of embryonic young, which speedily form their own investment to the extent of two or three chambers before breaking away from the enclosing shell.

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[1] 'Ueber Plastogamie bei Foram.,' *Sitz. Gesellsch. naturforsch. Freunde*, 1895, No. 10.

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CHAPTER IV

THE SHELL STRUCTURE OF THE FORAMINIFERA AND THEIR PLANS OF GROWTH

It is due to the fact that the Foraminifera present such an extensive variety of regular and beautiful forms that their shells are so much in favour with beginners in microscopy.

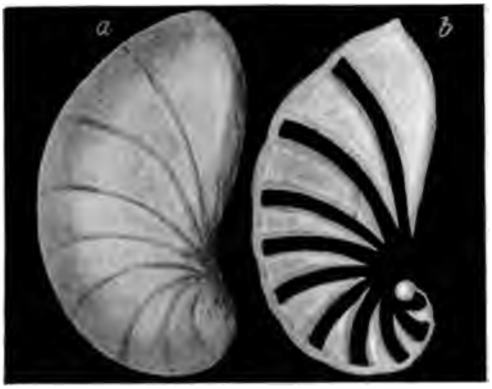

FIG. 18.

a, Test of Cristellaria crepidula (F. and M.); b, siliceous internal cast of the same species from 'flint-meal,' Upper Chalk. Highly magnified. *After Eley.*

The plan of the shell is dependent upon the arrangement of the continuously budded segments, and this is partially determined by the form of the primordial or initial chamber. It may be that of a straight series of segments, gradually increasing in size, as in *Nodosaria*; curved, as in *Marginulina*; or coiled, as in *Rotalia*.

The shell is, as it were, moulded upon the sarcode of the organism, and when we can obtain a cast of the shell—and this often happens in the case of the fossil Foraminifera—we have a perfect representation of the form of the animal (figs. 18, 19).

This feature of continuous segmentation of the body in the Foraminifera gave rise to the term *Polythalamia* (many-chambered), which was applied to this section of the order by Schultze. It will be seen subsequently (Chap. V.) how the early observers were misled by the external form of the Foraminifera, which, in spiral shells, such as *Cristellaria* and *Polystomella*, resemble those of cephalopods, as *Nautilus* and *Spirula*, except that they are much more minute. The internal appearances of the shells of the two groups are,

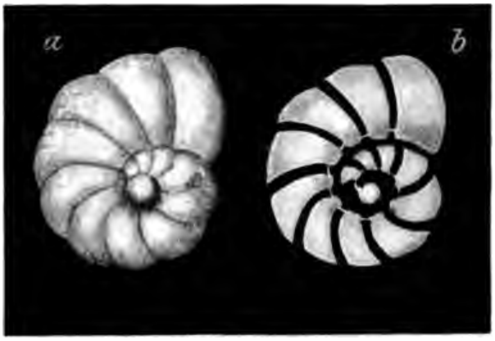

FIG. 19.—ANOMALINA AMMONOIDES (REUSS), UPPER CHALK.
After Eley.
a, Shell; *b*, internal cast. Highly magnified.

however, fundamentally different. All the chambers in the Foraminifera are occupied by the sarcode, whilst the cephalopod molluscs inhabit only the last chamber, leaving behind them in the earlier chambers merely a stolon or siphuncle. There is also another difference between the two groups, for while the septal face in the *Nautilus* is concave anteriorly, that in the foraminiferal shell is generally convex.

All Foraminifera are not multilocular, for some genera consist only of a single chamber at the most advanced stage of growth, as, for example, the chitinous form *Gromia*, or the calcareous *Lagena*. These were referred to as Monothalamia (single-chambered) in Schultze's classification.

THE SHELL STRUCTURE.

The shells of the Foraminifera, although formed by one of the simplest types of animal life, often show quite a complex structure. The outer shell-wall is non-tubulate only in the group of the Porcellanea or Imperforata; but in all the subdivisions of the Foraminifera the septa dividing the chambers are perforated by a tube or tubes called stolon canals or passages (fig. 20), by which the sarcode has free communication from chamber to chamber, and which allows the passage of the nucleus and other bodies contained within the protoplasm. These perforations of the septal walls are identical with the oral apertures seen on the last septal face of a foraminifer, and they constitute the external apertures of each chamber in succession as the segmental buds are added to the growing shell.

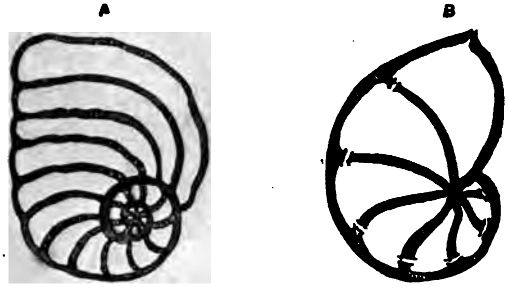

FIG. 20.—MEDIAN SECTIONS OF FORAMINIFERA, SHOWING STOLON PASSAGES THROUGH THE SEPTA.

A = Peneroplis, with imperforate shell-wall; B = Cristellaria, with perforate shell-wall.

The stolon passages are, as may be supposed,

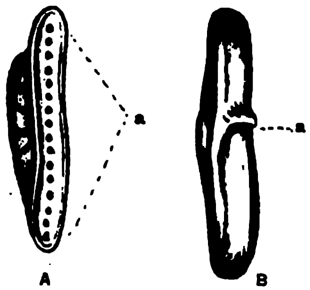

FIG. 21.

A, Apertures (*a*) on the septal face of Peneroplis pertusus.
B, Single aperture in Anomalina ariminensis.

more numerous in the imperforate group, which, generally speaking, has a series of apertures, as in

Peneroplis and *Orbitolites*; but are represented in the perforate group usually by a single opening or slit placed either on the inner or outer border of the shell in curved and coiled forms (fig. 21).

The group of the Perforata, as the name suggests, is distinguished by having a tubulated shell-wall. The tubules vary greatly both in number and also in diameter in the various genera. Usually the number of tubules varies, according to their size, in a proportionate manner; that is to say, the coarsely tubulated shell-wall has tubules placed at considerable intervals, whilst the finely perforate types have the shell-wall crowded with them. Those shells which have coarse tubules appear punctate when the surface is examined with a lens; but surface punctations are not always indicative of tubulation. An example with coarse tubuli is *Carpenteria*, in which the perforations have a diameter of ·1 mm. (fig. 22, A). The tubuli in *Amphistegina*

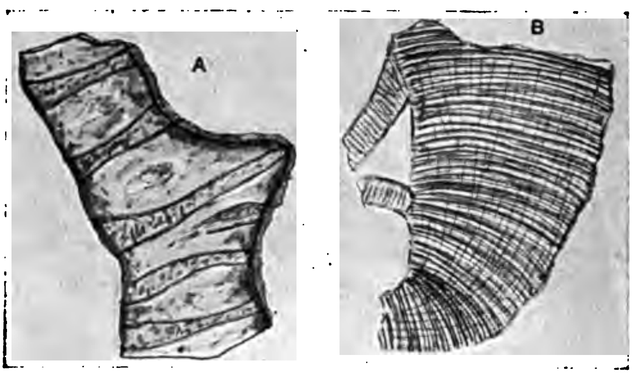

FIG. 22. × 332.
A = Coarse tubuli in the shell-wall of Carpenteria; B = fine tubuli in Amphistegina.
Original.

are very fine; they are about ·01 mm. in their transverse section (fig. 22, B). Certain parts of the shell are not tubulated in the hyaline or perforate group, and these layers may be regarded as an exogenous growth. This secondary structure is found only in the higher types of foraminiferal shells, and chiefly in those which have a double septum—that is, a complete and separate investment to each segment, as in *Rotalia* (fig. 23). It is seen

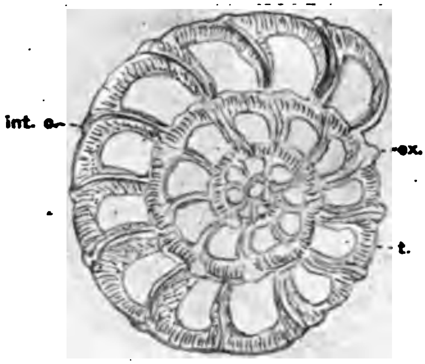

FIG. 23.—MEDIAN SECTION OF ROTALIA BECCARII, SHOWING INTERSEPTAL CANALS (int. c.), EXOGENOUS SHELL-LAYER (ex.), AND TUBULI (t.). × 30. *Original.*

on the external part of the shell, filling up sutural lines and umbilical depressions, and even forming a thick superficial coating to the shell or internal pillars, thereby adding greatly to the strength of the shell-wall. This layer often imparts an ornamental aspect to the surface of the shell in the form of beads or cones with the apices directed inwards, and the convex bases exposed, as in *Cycloclypeus* (fig. 24); or it may take the form of spurs and processes, as in *Calcarina* and *Tinoporus*. This exogenous shell layer, which was termed the intermediate or supplemental skeleton by Carpenter, is usually accompanied by a secondary stoloniferous system, called interseptal canals. Carpenter regarded this structure as a residual one, resulting from the imperfect junction of the septa and the supplementary skeleton, thereby causing certain portions of sarcode to be surrounded or partially cut off, although, in many cases, communication is probably kept up for nutritive purposes between them and the sarcode in the chambers of the shell.

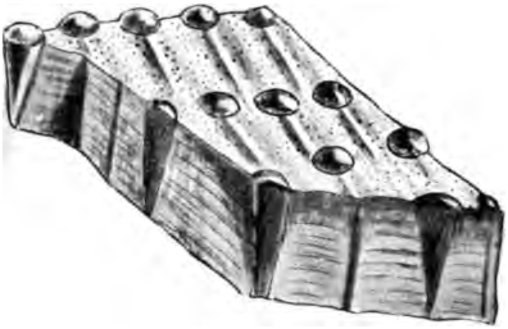

FIG. 24.—EXTERNAL LAYER IN CYCLOCLYPEUS CARPENTERI, SHOWING CONES OF NON-TUBULAR SUBSTANCE IN THE TUBULATED SHELL-WALL. Magnified. *After Carpenter.*

THE SHELL TEXTURE.

There are two principal types of shell texture in the Foraminifera, known as the *porcellanous* and the *hyaline*, which are usually taken as fundamental in classifying this order of animals. Two other prominent types of shell texture are also met with, the *arenaceous* and the *chitinous*; but these occupy a subsidiary place in the classification, for the genera which they comprise have representatives also in the hyaline and even the porcellanous groups.

1. *Imperforata or Porcellanea.* — This type of shell is, as the first name implies, without perforations in the shell wall, and the emission of the sarcode filaments (pseudopodia) is effected by the oral aperture only. The appearance of the shell is of a chalky white, generally glazed, and somewhat like porcelain. The shells, when seen by transmitted light, either in thin sections or, in the case of thin-shelled or young forms, when mounted in a medium like Canada balsam, appear of a pale horn-brown colour.

The mineral constituent of this type has long been supposed to be carbonate of lime in the form of aragonite. This appears from recent researches, and from the author's own experiments, to be extremely doubtful, and is more likely to be an intermediate mineral condition in which the organic element is intimately mixed with the mineral, and probably corresponding with the new mineral species Conchite. One powerful argument against the view that the porcellanous shell is composed of aragonite, which is a very unstable mineral, is the fact that certain calcareo-argillaceous rocks of Carbo-Permian age from Australia have recently been described, which are largely made up of the tests of a wild-growing or meandering form of *Nubecularia* in which the shell texture is exactly comparable with that of the recent porcellanous forms of the genus. The group of the imperforata is chiefly comprised within H. B. Brady's family of the MILIOLIDÆ.

2. *Perforata or Hyalina.*—These forms have a shell-wall which is perforated by minute tubes that pass to the external surface of the shell. The sarcode is extruded through these *tubuli*, and more or less covers the outer surface of the shell in the living animal, breaking up into reticulating and anastomosing pseudopodia; or in other cases is extruded directly from the tubuli as fine threadlike pseudopodia. The sarcode is also, as in the previous group, extruded through the aperture on the last septal face, and by other apertures which may exist on the external surface, such as the lateral series of perforations in *Polystomella*. The shell texture of this group is usually transparent and glassy, hence the term *hyalina*. The shell itself is composed of carbonate of lime in the form of calcite.

This group comprises the remainder of the Foraminifera, with the exception of the families of the GROMIIDÆ, the ASTRORHIZIDÆ, the LITUOLIDÆ, and a part of the family of the TEXTULARIIDÆ.

3. *Arenacea.*—This group is distinguished from the two previous in having a test not secreted by the organism, but constructed by it from adventitious particles picked up from its surroundings, and cemented together by a modification of the sarcode itself. In this respect it often resembles the curious little cases formed by the caddis worm, as, for

example, in *Rhizammina.* The material thus used in building the test may be sand grains (volcanic dust, quartz, calcareous, or glauconite grains), sponge spicules, or even the small tests of other Foraminifera, as in the case of *Rhizammina* and *Reophax.* In the genus *Carterina* the organism, however, does not rely on its surroundings for building material, but itself secretes innumerable delicate little fusiform spicules of a calcareous nature, with which to form its test.

A noticeable feature of all arenaceous Foraminifera is the invariably smooth internal lining to the test, which is glazed over with a film of chitinous or sarcodic material; the exterior, however, may vary from the neatly cemented and smooth-surfaced test of *Trochammina* to the coarsely agglutinated covering of a *Haplophragmium* or a *Reophax.*

Many arenaceous species are isomorphous, as regards external form, with species of other and distinct groups, such as *Haplophragmium* with *Anomalina*, or *Placopsilina* with *Nubecularia.*

That the arenacea is not a true zoological group is borne out by the fact that both arenaceous and hyaline types of shell structure exist in the same natural group or genus, as seen in *Textularia* or *Verneuilina.*

The whole of the families of the ASTRORHIZIDÆ, and the LITUOLIDÆ, and also a part of the TEXTULARIIDÆ, have arenaceous tests.

4. *Chitinous Forms.*—The members of the family

GROMIIDÆ have no calcareous shell, but are chitinous or horny in texture. This particular kind of investment is also found in a few forms in the genus *Miliolina* and in some usually arenaceous genera of the family TEXTULARIIDÆ.

Descriptive Terminology.

Before proceeding to discuss the subject of the various methods of growth in the foraminiferal shell it will be well to give a few of the terms used in describing the parts of the shell and their relations to one another. (See fig. 25.)

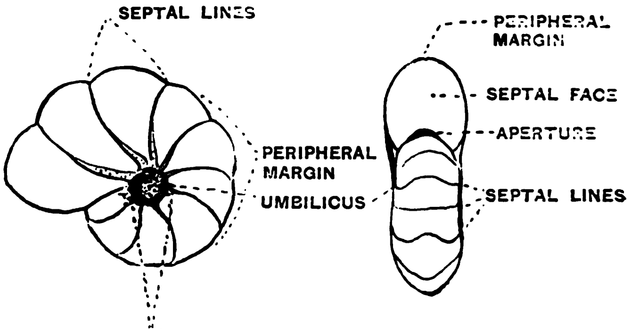

FIG. 25.—AN INVOLUTE NAUTILOID FORAMINIFER, NONIONINA DEPRESSULA, TO ILLUSTRATE THE EXTERNAL PARTS OF THE SHELL.

The outward indication of the septum is usually either a ridge or depression—the *septal line*; sometimes the suture is flush with the shell surface, and is then only recognised by a difference in its translucency.

The superficial area of the septum is called the *septal plane* or *septal face*.

In the nautiloid forms the entire shell has two *lateral faces* and a *peripheral margin*.

The septal plane has three *angles*, a *peripheral* and two *umbilical angles*.

Each segment has three *margins*, a *posterior* (nearest the primordial chamber), an *anterior* (nearest the oral aperture), and a *peripheral*.

In trochoid shells the surface on which the primordial segment appears is termed the *posterior* or *superior surface*, whilst the opposite, usually flat side, is the *inferior surface*.

In the nodosarian type the *lateral aspect* is that seen when the shell is viewed lengthwise; the *oral* or *anterior aspect* being that seen when the ultimate septal face is presented to view.

In compressed forms, as *Lingulina*, we speak of the edge of the shell as its *periphero-lateral aspect*.

The two ends of the rectilineal shell are referred to as the aboral (=proximal) extremity, and the oral (=distal) extremity.

Plans of Growth.

We have already seen that certain of the Foraminifera, as *Lagena* and *Gromia*, are single-chambered, which is the result of a complete separation of the segments of sarcode, each having a distinct shell. When, however, as is usually the case, the sarcode body consists of many connected segments, these are arranged according to a definite plan or tendency inherent in the primordial and early chambers; and the position of the aperture of each chamber, which subsequently becomes a stolon connection, determines the axial direction of growth for the succession of chambers. A lageniform chamber with the aperture arranged centrally would be followed by a rectilinear series of chambers, each connected by a central stolon, and this would give rise to a form like *Nodosaria*.

There is every gradation between the rectilinear and the spiral mode of growth, and an alteration in the plan often occurs at a later stage of the growing shell, some genera embracing the two kinds, as *Peneroplis*, which in several of its species commences with a spiral followed by a straight series of chambers.

Spirally formed shells present many modifications, the simplest consisting of a coiled tube wound on the same plane, as in *Spirillina*. Or the tube may be wound in a conical manner, as in *Involutina*. Segmented spiral shells, when coiled in one plane, so that in the peripheral aspect they are equilateral, are termed nautiloid; when the shell is more or less conical, the primordial chamber occupying the apex, the shell is trochoid or turbinoid. The whorls in the latter instance are only visible on one face, the superior. The coils of the spiral may be either evolute, as in *Operculina*, which has the whorls entirely exposed on both surfaces, or involute, as in *Polystomella* or *Cristellaria*, in which the shell is covered up at each successive turn, usually only the last whorl being visible. In the last-named genus, when the specimen is megalospheric—that is, with a large central chamber—there is a boss generally visible at the umbilical centres of the shell, the exterior of the megalosphere; for this is usually left uncovered by the involving series of chambers of later growth. Sometimes the coiling of the shell is rapid, and then there are few chambers to each turn, as in *Globigerina*.

Leaving the forms which have a series of chambers arranged along a single axis, we come to the biserial forms, those which have two rows of segments side by side, which are not connected with each other on the same line of growth, but are connected by stolons to the segments above and below on the *opposite* side, as in *Textularia*. Other forms are in a similar manner arranged in three rows (triserial), as in *Tritaxia*.

Another plan, the cyclical method of growth, seems to be derived from the spiral, for both in *Orbitolites* and *Cycloclypeus* the earlier segments show a tendency to a spiral manner of growth, but this soon changes into the concentric by the segments budding, not on one side only, but all round, so as to form a ring or annulus of chamberlets.

There are many other fundamental forms—for instance where the axis has, so to speak, been twisted during the growth of the shell, as in *Bulimina*. Others are represented not only by the apparent twisting of the axis of growth, but also by a folding and inrolling, which are represented by the forms *Cassidulina* and *Ehrenbergina*.

The plans of growth in the Foraminifera formed the basis of D'Orbigny's classification, and he grouped the various forms in seven orders[1] (fig. 26). These are given below, to afford an idea of the great variation in the foraminiferal shell.

1. Monostega.—Body consisting of a single segment: shell of one chamber. Flask-shaped, as in *Lagena*; spherical, as in *Orbulina*; cylindrical and coiled, as in *Cornuspira*.

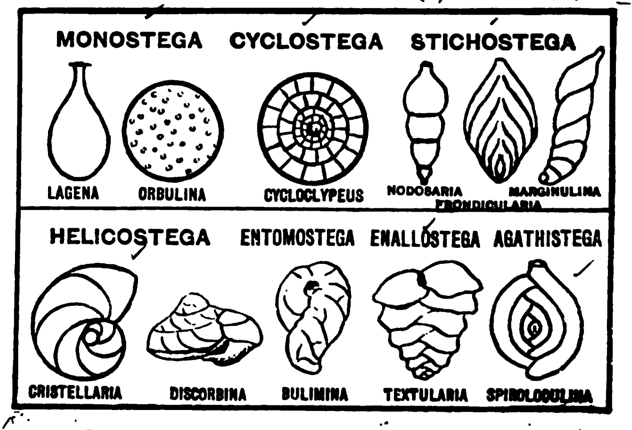

Fig. 26. D'Orbigny's Classification of the Foraminifera, illustrated by Selected Types.

2. Cyclostega.—Body discoidal, composed of concentric lines of segments, simple or multiple, never spiral. Examples: *Orbitolites*, *Cycloclypeus*.

3. Stichostega.—Body composed of segments disposed in a single line. Shell consisting of a linear series of chambers. Straight, as in *Nodosaria*; curved, as in *Marginulina*.

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[1] *Cours Élémentaire de Paléontologie et de Géologie Stratigraphique*, vol. ii. p. 189. Paris, 1852.

4. HELICOSTEGA.—Body consisting of a spiral series of segments. Shell made up of a number of convolutions. The spiral may be either nautiloid (flat), as in *Cristellaria*, or turbinoid (conical), as in *Discorbina*.

5. ENTOMOSTEGA.—Body consisting of alternate segments spirally arranged: shell chambers disposed on two alternating axes forming a spiral. Example: *Bulimina*.

6. ENALLOSTEGA.—Body composed of alternate segments not forming a spiral; chambers arranged on two or three axes which do not form a spiral. Examples: *Textularia*, *Bolivina*.

7. AGATHISTEGA.—Body consisting of segments wound round an axis: chambers arranged in a similar manner, each investing half the entire circumference. Examples: *Biloculina*, *Miliolina*.

Besides the foregoing types there is another method of growth, which is provided for in Schultze's classification of the Rhizopoda, in which the segments are arranged without any general plan, apparently heaped together in an acervuline mass, as in *Gypsina*.

Schultze's classification is as follows:—

B. TESTACEA (including *Foraminifera* and *Arcellina*).

1. MONOTHALAMIA

(=Monostega of D'Orbigny, and Arcellina).

2. Polythalamia.

A. *Helicoidea* = Cyclostega, D'Orb. · Helicostega, D'Orb. · Entomostega, D'Orb. · Enallostega, D'Orb. · Agathistega, D'Orb.

B. *Rhabdoidea* = Stichostega, D'Orb.

C. *Soroidea*. Contains the genus *Acervulina*, Schultze (= *Gypsina*).

The above classificatory schemes, based entirely on external form, do not allow for those types of Foraminifera which change their plan of growth once or even twice during their development. For example, [illegible] is at first of a nautiloid-spiral form, then biserial, and afterwards uniserial, thus possessing characters which belong to orders 4, 6, and 8 of D'Orbigny's classification, in succession. Or [illegible], which is at first milioline and then planospiral. Such complex forms are spoken of as *dimor-*[illegible] and [illegible].[1]

[illegible].—When two or more forms distinct in shell structure exhibit similar external outlines they are said to be isomorphous.

As examples among the [illegible] of Foraminifera the following may be quoted:—

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[1] [illegible] "dimorphic" and "dimor-[illegible] different meaning.

PORCELLANOUS.	HYALINE.
Cornuspira	*Spirillina*
Peneroplis	*Operculina*
Orbiculina	*Heterostegina*
Orbitolites	*Cycloclypeus*
Alveolina	*Fusulina*

As examples among *Species* the following are given :—

PORCELLANOUS.	HYALINE.	ARENACEOUS.
Cornuspira involvens	*Spirillina vivipara*	*Ammodiscus incertus*
Nubecularia tibia	*Nodosaria pyrula*	*Reophax nodulosa*
Peneroplis cylindracea	*Cristellaria elegans*	*Haplophragmium agglutinans*

CHAPTER V

THE IDEAS OF THE EARLY AUTHORS REGARDING THE FORAMINIFERA

It will now be interesting to consider the various ideas of the early writers concerning the nature of Foraminifera; and thus, by following the gradual progress of thought which eliminates the erroneous, we may more clearly see the reasons for the conclusions arrived at up to the present time.

Very little seems to have been known about the Foraminifera before the time of Linnæus. The discoid (coin-shaped) form known as the nummulite, and which largely constitutes some of the Eocene limestones of Egypt and elsewhere, appears to have first attracted attention, presumably on account of its unusually large size. Probably the first writer who noticed them was Strabo, who mentions their resemblance to lentils; and, since they were found round the bases of the pyramids, they were fabulously supposed to be the pulse-food dropped by the workmen, which afterwards had become petrified.

Long after this many other observers gave descriptions of Nummulites, notably Agricola in 1558; Conrad Gesner in 1565; Scheuchzer in 1697–8, who described them as 'Lentes lapideæ striatæ,' &c.; Edward Lhuyd in 1699; and Brueckmann in 1727, who gave a good figure of his 'lapidus numismalis,' which is a fine example of *Nummulites complanata.*

One of the first naturalists to notice the minuter Foraminifera which are so frequent in shore sands and the later Tertiary deposits was Beccarius (J. Beccari), who, in 1731, described the various minute shells he found in the yellow Pliocene sands near Bologna. Beccarius also mentions the shore sand of Rimini, on the Adriatic coast, a locality which afterwards yielded many interesting specimens to another observer, Janus Plancus (Giovanni Bianchi), who published his well-known memoir in 1739, on the minute shells from the shore sand at Rimini. In this collection there are many characteristic Foraminifera, and they are referred to generally as '*Cornua hammonis.*' The figures which Plancus gave show that these forms belong to the genera *Nodosaria*, *Cristellaria*, *Rotalia*, and *Polystomella.* Some of Plancus's specimens were evidently derived from, or washed out of, the Tertiary clay cliffs near at hand.

The early observers, it should be noted, classed the minute shells of the Foraminifera with the *Nautilus* and *Serpulæ*, under the supposition that they were small individuals of the larger marine shells.

The figures and descriptions given by Plancus (1739), Gualtieri (1742), and Ledermüller (1760-68) were assigned specific names by Linnæus in the 12th edition of his 'Systema Naturæ' (1766-67), and in Gmelin's edition of the same work (1788-93) the forms given by Spengler (1781) and Schröter (1793) were included.

Another observer, Soldani (1780-98), described a large number of recent and fossil forms from the shores of the Mediterranean, but he did not adopt the binomial nomenclature of Linnæus's system.

The work written by Walker, Jacob, and Boys on the minute shells from the sand of Sandwich Bay (1784) made us familiar with the ordinary British species of Foraminifera, but they were still referred to such genera as *Nautilus* and *Serpula*.

Montagu, in the 'Testacea Britannica' (1803), also retained these generic names for the ordinary coiled and straight forms, whilst Fichtel and Moll (1798) published an important memoir on the coiled shells which they included in the genus *Nautilus*.

In his 'Cours de Zoologie' Lamarck, in 1812, referred the Foraminifera either to the group of molluscs known as Cephalopods or to the Corals, according to the external appearance of the shell. The genera established by Lamarck in this work are among the most important now in general use, as *Nodosaria*, *Cristellaria*, and *Rotalia*, although the zoological position they were then thought to occupy is incorrect.

De Montfort (1808), De Blainville, and Defrance (1816) figured and specified many new forms, but they also retained the old idea of grouping them with the Cephalopods and other organisms higher in type of structure than the Protozoa. A great advance, however, was made by A. D. d'Orbigny in his systematic view of the class Cephalopoda (1826), in which he separates the Foraminifera from the rest of the group.[1] D'Orbigny divided the class Cephalopodes as follows: Order I., Cryptodibranches; Order II., Siphonifères; Order III., Foraminifères. The last-named order was distinguished by having a chambered shell, with communications between them by means of holes or foramina in the septa. Hence the name FORAMINIFERA (hole-bearers). The foramina are in reality the stolon passages between the chambers, and not the tubules or perforations of the outer shell wall, as is sometimes mistakenly asserted, which are only characteristic of one of the divisions of the Foraminifera. This distinction will be seen on reference to fig. 20.

Various other names, such as TREMATOPHORES, POLYTHALAMIA, and THALAMOPHORA, have been used for designating this group, but the term FORAMINIFERA has obtained the widest acceptance among naturalists.

Finally, to Dujardin (1835) the credit is due for conclusively proving that the Foraminifera are not cephalopodous molluscs, but that they are of much lower organisation, and that their relationship is with the Rhizopoda.

Since that time Ehrenberg, Williamson, Carpenter, Carter, Parker, and Rupert Jones, as the pioneers in the discovery of facts concerning this important group of animals, have been followed by a large number of enthusiastic workers. There yet remains, however, much to be accomplished in the elucidation of the life history of the Foraminifera, as well as in making careful observations regarding their distribution in time and space.

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[1] See 'Tableau Méthodique de la Classe des Céphalopodes,' in *Annales des Sciences Naturelles*, vol. vii. p. 245.

CHAPTER VI

THE CLASSIFICATION OF THE FORAMINIFERA

Every classification is more or less artificial and imperfect, and this must especially be the case with a variable order of animals like the Foraminifera. It is inconceivable that any type of animal life underwent a series of changes in any direct line for very long, without interference from dissimilar influences, the stronger prevailing; and thus a devious path would be tracked out, defying all our attempts to place certain groups in definite order or sequence with regard to others. Instead of a gradually branching phylogenetic tree we should, to be accurate, have to make an arrangement taking the form of a net, in which the species were represented by the knots which unite the threads, the latter standing for the series of intermediate forms connecting the species. A difficulty would arise in determining where the knots were to be placed—that is to say, what were the types to be retained as such—and the extent of the connecting threads.

The division into genera and species is the outcome of a selection of what the systematist is pleased to regard as types, whilst the intermediate conditions are either considered as varietal or, what is more often the case, ignored altogether. It is possible to take a large series of a common form from one locality and to arrange it gradationally. By this means we can sometimes determine that the two extremities of the series have as high a specific value as many so-called species which occur but rarely. If this can be demonstrated with a series of specimens from a single locality, it is easy to conceive what an enormous variation obtains with regard to what we imagine to be a specific type over the whole of the faunal area. Although this is true of many of the Foraminifera, there are numerous type forms which are well worthy of a specific name, for they present marked characters of their own, and have shown persistent characters throughout many successive geological ages.

Notwithstanding all that has been written against the principle of using the character of shell-texture as a prime factor in the classification of the Foraminifera, this method has very much to recommend it; and it also, besides its convenience, possesses some merits for being a natural arrangement, so far as it brings together certain tribes and types which are clearly related to one another, even if they have not emanated from the same prototype.

The classification of H. B. Brady (1884) is based on the earlier systems of Reuss (1861), Carpenter, Parker, and Jones (1862), and of Rupert Jones (1876). The chief differences in Brady's classification are the amalgamation of the families and the institution of sub-families; the creation of a new family, the ASTRORHIZIDÆ, which received large accessions by the examination of the rich collections dredged by the 'Challenger;' and the removal of the TEXTULARIDA and the BULIMINIDA to a separate family, the TEXTULARIIDÆ. The retention of this latter group would seem to throw doubt on the utility of regarding differences of shell structure as a canon of classification, since this family contains examples of both types of structure, the arenaceous and the hyaline. There is also another weakness in the arrangement, which has been lately emphasised by Continental systematists, as Eimer and Fickert, and was also remarked upon by Brady himself—namely, the presence, in the family of the LITUOLIDÆ, of numerous arenaceous isomorphs of the hyaline forms.

But, with the exception of these perhaps unavoidable discrepancies, Brady's classification has the merit of being quickly and easily understood by the student of Foraminifera, and it certainly holds the field in point of the number of writers who still make use of it.

It will be useful, however, to insert at this place three of the latest classifications of Foraminifera.

Dr. Bütschli (1880) divides the Rhizopoda, as did Max Schultze, into two sub-orders, *Amœbæa* (Nuda, Schultze) and *Testacea*.

TESTACEA, M. Schultze. (*Thalamophora*, R. Hertwig.)

A. Tribe.—IMPERFORATA, Carpenter.

Family 1. *Arcellina*, Ehrenberg.
,, 2. *Euglyphina*, Bütschli.

Family 3. *Gromiina*, Bütschli.
„ 4. *Amphistomina*, Bütschli.
„ 5. *Miliolidina* (*Miliolidea* Reuss, + pars *Lituolidarum*).
„ 6. *Peneroplidina*, Reuss.
„ 7. *Orbitolitina* (*Orbitulitidea*, Reuss).
„ 8. *Arenacea*, Bütschli.

B. Tribe.—Perforata, Carpenter + pars *Lituolidarum*.

Family 1. *Rhabdoina*, Schultze.
„ 2. *Polymorphinina*, Bütschli.
„ 3. *Globigerinina*, Carpenter.
  Sub-family (*a*) Globigerinæ, Carp.
  „ (*b*) Cryptostegia, Reuss.
  „ (*c*) Textularidæ, Carp.
  „ (*d*) Rotalinæ, Carp.
Family 4. *Nummulitinæ* (*Nummulinida*, Carpenter), emend. Bütschli.
  Sub-family (*a*) Involutinæ, Bütschli.
  „ (*b*) Pulleninæ, Bütschli.
  „ (*c*) Nummulitidæ.
  „ (*d*) Fusulinidæ, Möller.
  „ (*e*) Cycloclypidæ, Bütschli.

The difficulty in accepting this system, although the external form has been carefully considered, lies in the fact that in the same family such distinct types as the Textularids and the Rotalines are associated, and which have very little in common as regards the minute structure of the shell-wall. The same may also be said for the fourth family of this arrangement.

Neumayr's classification (1887) recognises three main groups, namely, the irregularly formed arenaceous types (Astrorhizids); the regularly formed arenaceous types; and the calcareous types. The 2nd and 3rd groups are again divided into two parallel and isomorphous series which comprise the following fundamental types: A, *Cornuspira*; B, *Textularia*; C, *Lituola*; D, *Fusulina*.

In 1895 Dr. L. Rhumbler published his 'Entwurf eines natürlichen Systems der Thalamophoren.' He divides the group into ten Families, and by a diagram points out a probable evolution of types from simple arenaceous tubes to the highly differentiated Rotaline shell-structure.

The Families are numbered in the following order:—

1. Rhabdamminidæ.
2. Ammodiscidæ.
3. Spirillinidæ.
4. Nodosinellidæ.
5. Miliolinidæ.
6. Orbitolitidæ.
7. Textularidæ.
8. Nodosaridæ } Lageninæ.
9. Endothyridæ }
10. Rotalidæ.

Rhumbler considers that the *Lageninæ* were derived from the nodosarine type of shell by a permanent separation of the chambers.

Eimer and Fickert (1899) have published an elaborate and well-illustrated treatise on the morphology and relationship in the Foraminifera,[1] and propose a new classification of the group. There are many strong points in this scheme which deserve

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[1] 'Die Artbildung und Verwandtschaft bei den Foraminiferen,' *Tübinger Zoologische Arbeiten*, Band iii. No. 6. 1899.

careful consideration, such as the grouping together of genera which are morphologically similar, but which have differences of shell-structure. According to these authors the shell-structure should be subordinated to the form and manner of segmentation in the animal, and this is in accordance with accepted zoological principles. They divide the Foraminifera into as many as thirty-seven families. To give an example of the method used in classifying the group, the Tribe Stichostegia (Eimer and Fickert) is divided into, A, PSAMMATOSTICHOSTEGIA, including the Families HYPERAMMINIDÆ (genera *Hyperammina*, *Reophax*, and *Hormosina*) and ASCHEMONELLIDÆ (genera *Aschemonella* and *Ramulina*): B, TITANOSTICHOSTEGIA, represented by the Family NODOSARIIDÆ and genus *Nodosaria*. In division A the test is arenaceous, and in B it is calcareous. There is, however, no apparent reason given for including *Ramulina* in Division A, since it is essentially calcareous. Very diverse forms are here brought together, such as *Cristellaria*, *Cassidulina*, and *Sagraina*, which are morphologically distinct.

The relationship of the different types of form in Foraminifera is so complex and interwoven that, from whatever standpoint we may approach the subject, we are certain to meet with numerous difficulties which prevent our making a satisfactory classification. We may expect a more hopeful state of things when further light has been thrown upon the relation of environment to shell structure, and dimorphism to specific forms.

Meanwhile we are perforce necessitated to accept a simple and ready, although more or less artificial, system, such as that used by H. B. Brady in his Report on the 'Challenger' Foraminifera.

The idea has lately been advanced by certain authors that the earlier types of Foraminifera were probably simple straight sandy tubes, without partitions, followed by coiled and segmented or chambered tests, and subsequently in later times by a secreted shell of a calcareous nature. Detailed observation, however, often refutes the best formulated ideas, and it appears to have done so in this case. Recent researches in the Cambrian Rocks of New Brunswick and England have resulted in the discovery of the following among other generic types: *Lagena*, *Nodosaria* (including *Glandulina*), *Cristellaria*, *Globigerina*, and *Spirillina*. All of these forms have well-developed shell structures of a calcareous nature. With regard to the forms with arenaceous tests, on the other hand, we find no evidence of these until we reach the Upper Silurian deposits, when we meet with *Hyperammina*, and the calcareo-arenaceous genus *Stacheia*.

The classification which will be followed in the succeeding pages of this book is that which has been gradually evolved principally by the British school of Rhizopodists—Wallich, Parker and Jones, Carpenter and H. B. Brady—and which has been largely emended and added to by the last-named author.[1] With regard to the utility of this simpler method of classifying the Foraminifera by the selection of central types, Brady says: 'The study of the Foraminifera as assemblages of forms grouped round a comparatively small number of central or typical species, as advocated by Carpenter and his colleagues, is, I am convinced, the only means of arriving at a correct understanding of the biological relations of the group; but this mode of treatment, whilst determining the general lines of classification, furnishes no direct basis for the construction of a synopsis suited to the requirements of the systematic zoologist. The scheme which I now venture to propose differs in many respects somewhat widely from that foreshadowed by the authors referred to, but in its essential elements there is little or nothing that is incompatible with the conclusions they have so ably expounded; and I have the satisfaction of knowing that it has their general approval. Every attempt to arrange in single series a class of organisms of which the constituent groups are apt to run in parallel lines, or even sometimes to form, morphologically speaking, independent circlets, is of necessity open to objection at one point or other; and the aim of the systematist is well attained if the anomalies and inconsistencies are slight, and are confined to matters of small zoological importance.'[1]

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[1] See Report *Challenger*, vol. ix. 'Zoology,' 1884, pp. 60-76.

Sub-kingdom—PROTOZOA.
Class—RHIZOPODA.
Order—*Foraminifera* (Reticularia).

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[1] See Report *Challenger*, vol. ix. 'Zoology,' 1884, p. 58.

Family I.—GROMIIDÆ.

Division A.—Aperture single, terminal. Genera—*Lieberkuehnia*, *Mikrogromia*, *Gromia*, *Diaphoropodon*.

Division B.—With mouth at each end of test. Genera—*Shepheardella*, *Amphitrema*.

Family II.—MILIOLIDÆ.

Sub-family 1.—Nubeculariinæ.

Genera—*Squamulina*, *Calcituba*, *Nubecularia*.

Sub-family 2.—Miliolininæ.

Genera—*Biloculina*, *Fabularia*, *Spiroloculina*, *Miliolina* (sub-genera—*Dillina*, *Triloculina*, *Trillina*, *Quinqueloculina*, *Pentellina*, *Idalina*, *Adelosina*, *Periloculina*, *Massilina*, *Heterillina*, *Sigmoïlina*).

Sub-family 3.—Hauerininæ.

Genera — *Articulina*, *Vertebralina*, *Ophthalmidium*, *Hauerina*, *Planispirina*.

Sub-family 4.—Peneroplidinæ.

Genera—*Cornuspira*, *Peneroplis* (sub-genera—*Monalysidium*, *Archiacina*), *Orbiculina* (sub-genus—*Meandropsina*), *Orbitolites*.

Sub-family 5.—Alveolininæ.

Genera—*Alveolina* (sub-genus—*Flosculina*), *Lacazina*.

Sub-family 6.—Keramosphærinæ.

Genus—*Keramosphæra*.

Family III.—ASTRORHIZIDÆ.

Sub-family 1.—ASTRORHIZINÆ.

Genera—*Astrorhiza*, *Pelosina*, *Storthosphæra*, *Dendrophrya*, *Syringammina.*

Sub-family 2.—PILULININÆ.

Genera — *Pilulina*, *Technitella*, *Rhaphidoscene*, *Bathysiphon.*

Sub-family 3.—SACCAMMININÆ.

Genera—*Psammosphæra*, *Sorosphæra*, *Saccammina.*

Sub-family 4.—RHABDAMMININÆ.

Genera—*Jaculella*, *Hyperammina*, *Marsipella*, *Rhabdammina*, *Aschemonella*, *Rhizammina*, *Sagenina*, *Botellina*, *Haliphysema.*

Family IV.—LITUOLIDÆ.

Sub-family 1.—LITUOLINÆ.

Division A.—Non-labyrinthic tests. Genera—*Reophax*, *Haplophragmium* (sub-genus—*Coskinolina*), *Placopsilina*, *Crithionina*, *Verrucina.*

Division B.—Chambers labyrinthic. Genera—*Haplostiche*, *Lituola*, *Bdelloidina*, *Haddonia*, *Polyphragma.*

Sub-family 2.—TROCHAMMININÆ.

Genera—*Thurammina* (sub-genus—*Thuramminopsis*), *Hippocrepina*, *Hormosina*, *Ammodiscus*, *Trochammina*, *Carterina*, *Webbina.*

Sub-family 3.—ENDOTHYRINÆ.

Genera—*Nodosinella*, *Stacheia*, *Involutina*, *Orbitolina*, *Conulites*, *Endothyra* (sub-genera—*Bradyina*, *Cribrospira*).

Sub-family 4.—LOFTUSIINÆ.

Genera—*Cyclammina*, *Loftusia*.

Family V.—TEXTULARIIDÆ.

Sub-family 1.—TEXTULARIINÆ.

Genera — *Textularia*, *Cuneolina*, *Verneuilina*, *Tritaxia*, *Chrysalidina*, *Bigenerina* (sub-genus—*Siphogenerina*), *Pavonina*, *Spiroplecta*, *Gaudryina*, *Valvulina*, *Clavulina*.

Sub-family 2.—BULIMININÆ.

Genera—*Bulimina*, *Virgulina*, *Bifarina*, *Bolivina*, *Mimosina*, *Pleurostomella*.

Sub-family 3.—CASSIDULININÆ.

Genera—*Cassidulina* (sub-genus—*Orthoplecta*), *Ehrenbergina*.

Family VI.—CHEILOSTOMELLIDÆ.

Genera—*Ellipsoidina*, *Cheilostomella*, *Seabrookia*, *Allomorphina*.

Family VII.—LAGENIDÆ.

Sub-family 1.—LAGENINÆ.

Genus—*Lagena*.

Sub-family 2.—NODOSARIINÆ.

Genera — *Nodosaria* (sub-genera — *Glandulina*, *Dentalina*), *Lingulina*, *Frondicularia*, *Rhabdogonium*, *Marginulina*, *Vaginulina*, *Rimulina*, *Cristellaria*.

Dimorphous genera—*Amphicoryne*, *Lingulinopsis*, *Flabellina*, *Amphimorphina*, *Dentalinopsis*.

Sub-family 3.—POLYMORPHININÆ.

Genera—*Polymorphina* : dimorphous form, *Dimorphina*. *Uvigerina* : dimorphous form, *Sagraina*.

Sub-family 4.—RAMULININÆ.

Genera—*Ramulina*, *Vitriwebbina*.

Family VIII.—GLOBIGERINIDÆ.

Genera — *Globigerina*, *Orbulina*, *Hastigerina*, *Pullenia*, *Sphæroidina*, *Candeina*.

Family IX.—ROTALIIDÆ.

Sub-family 1.—SPIRILLININÆ.

Genus—*Spirillina*.

Sub-family 2.—ROTALIINÆ.

Genera—*Patellina*, *Cymbalopora* (sub-genus—*Tretomphalus*), *Discorbina*, *Planorbulina*, *Truncatulina*, *Anomalina*, *Carpenteria*, *Rupertia*, *Pulvinulina*, *Rotalia*, *Calcarina*.

Sub-family 3.—TINOPORINÆ.

Genera — *Tinoporus*, *Gypsina*, *Miogypsina*, *Polytrema*.

Family X.—NUMMULINIDÆ.

Sub-family 1.—FUSULININÆ.

Genera—*Fusulina* (sub-genera—*Hemifusulina*, *Fusulinella*), *Schwagerina.*

Sub-family 2.—POLYSTOMELLINÆ.

Genera—*Nonionina*, *Polystomella* (sub-genus—*Faujasina*).

Sub-family 3.—NUMMULITINÆ.

Genera—*Archædiscus*, *Amphistegina*, *Operculina*, *Heterostegina*, *Nummulites*, *Assilina.*

Sub-family 4.—CYCLOCLYPEINÆ.

Genera—*Cycloclypeus*, *Orbitoides* (sub-genera—*Discocyclina*, *Lepidocyclina*).

CHAPTER VII

THE FAMILY GROMIIDÆ

The characteristics of the test in the Gromiidæ are a chitinous or skinlike investment, without superficial perforations, and with an aperture for the emission of sarcode either at one end of the test (Section A) or at both ends (Section B). The investment is either thin and closely adherent to the body of the animal, as in *Lieberkuehnia*, or more rigid, as in *Gromia*. In the latter genus it forms a distinct test, whilst in the former genus the covering or membrane alters its shape in accordance with the changes in the shape of the body of the animal. The colour of the investment in this family ranges from hyaline to yellowish or light brown, and it is sometimes encrusted with adventitious particles, such as sand grains or diatoms.

Many of the lobose and filose kinds of Protozoa are closely allied to members of this family, such as *Difflugia* and *Euglypha*, and the only difference between them, which at the best is slight, is the habit and form of the extended pseudopods, which in the Foraminifera are characterised by their fine threadlike and anastomosing characters.

No Fossil representatives.

SECTION A.—GENERA IN WHICH THE APERTURE IS SINGLE AND TERMINAL.

Lieberkuehnia, CLAPARÈDE and LACHMANN.

Test rather large, ovate or pyriform, with the mouth in a depression at the middle of the broad end, which is more or less four-lobed. Circulation of protoplasmic granules rapid.

EXAMPLE.—*L. Wageneri*, Clap. and Lachm., 'Mém. Inst. Nat. Génevois,' vol. xvi. 1859, p. 465, pl. xxiv. Habitat, fresh-water ponds in Germany. (Plate 1, fig. A.)

Mikrogromia, R. HERTWIG.

Test minute, ovate; somewhat bilateral, owing to the one-sided position of the produced collar-like mouth. Cavity of the test only partially filled. Pseudopodia given off from an oral column. Often found in colonies.

EXAMPLE.—*M. socialis*, Archer sp. (*Gromia socialis*), Archer, 'Quart. Journ. Micr. Sci.' N.S., vol. ix. 1869, p. 27, pl. xx. figs. 7–11. See also 'Ueber *Mikrogromia*,' by R. Hertwig, 'Arch. Mikr. Anat.' vol. x. 1874, supplement, vol. i. Habitat, fresh water. Diameter of separate tests, ·015 to ·025 mm. (Plate 1, fig. B.)

Gromia, DUJARDIN.

Test large, ovate or rounded, symmetrical in form, flexible. Mouth terminal; pseudopodia much reticulated. Possessing one or more nuclei; contractile vacuole often wanting.

Species of this genus are sometimes found in fresh water, and sometimes are marine.

Examples from Fresh Water.—*G. fluviatilis*, Dujardin, 'Hist. Nat. Zooph. Infusoires,' 1841, p. 255, pl. i. fig. 17; pl. ii. fig. 182. This species measures from ·09 to ·25 mm. in breadth. Found upon *Ceratophyllum*, an aquatic plant growing in stagnant water.

G. hyalina, P. Schlumberger, 'Ann. Sci. Nat.,' ser. 3, vol. iii. 1845, p. 255. This species has a breadth of ·03 to ·05 mm.

Marine Examples.—*G. oviformis*, Dujardin, 'Ann. Sci. Nat. Zool.,' ser. 2, vol. iv. 1835, p. 345, pl. ix. figs. 1, 2. Measures 1 to 2 mm. in length. Found among marine plants. (Plate 1, fig. C.)

G. Dujardinii, Schultze, 'Organismus Polythal.' 1854, p. 55.

Diaphoropodon, Archer.

Test large, ovate; built up of foreign bodies (diatoms and the like). Pseudopodia of two sorts; the one long, branching and arborescent, issuing from the mouth; the other fine and hairlike, not reticulated, springing from between the shell particles (perhaps not true pseudopodia). Nucleus single, large. Contractile vacuole present.

Example.—*D. mobile*, Archer, 'Quart. Journ. Micr. Sci.,' N.S., vol. ix. 1869, p. 394, pl. xx. fig. 6, and vol. x. 1870, p. 123. Habitat, fresh-water pools in Ireland. (Plate 1, fig. D.)

SECTION B.—GENERA WITH APERTURES AT BOTH ENDS OF THE TEST.

Shepheardella, SIDDALL.

Test hyaline, elongate, tubular, cylindrical or flattened, ends slightly tapering towards the apertures. Nucleus large and complex.

EXAMPLE.—*S. tæniformis*, Siddall, 'Quart. Journ. Micr. Sci.,' N.S., vol. xx. 1880, p. 131, pl. xv. Habitat, marine, in shore pools, on marine algæ. (Plate 1, fig. E.)

Amphitrema, ARCHER.

Test more or less covered by foreign arenaceous particles; apertures at opposite ends of the test and provided with a rimlike neck, giving off two tufts of elongate, linear, branched, pellucid pseudopodia.

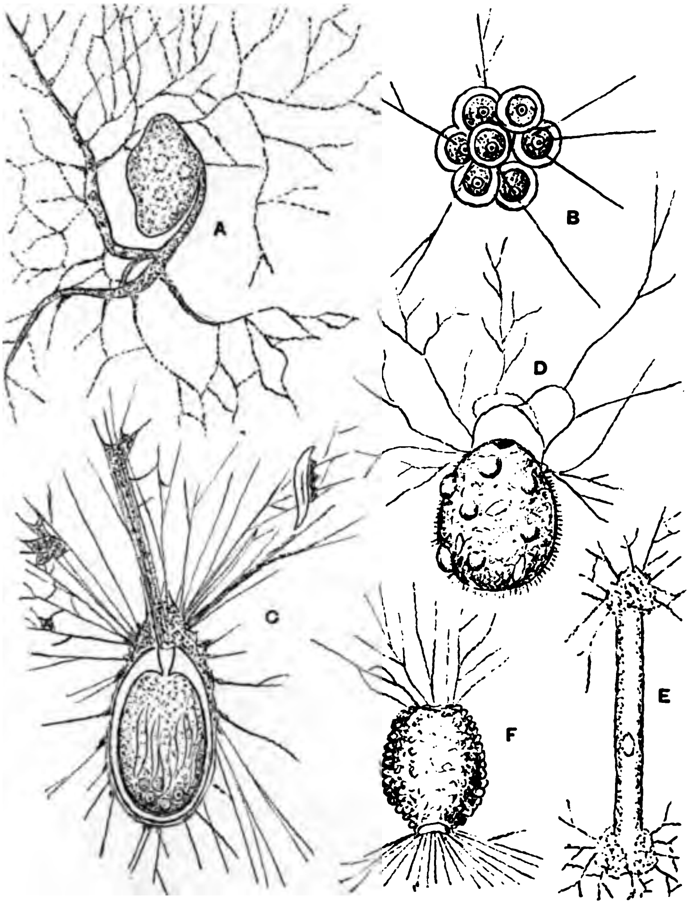
EXAMPLE.—*A. Wrightianum*, Archer, 'Quart. Journ. Micr. Sci.,' N.S., vol. x. 1870, p. 122, pl. xx. figs. 4, 5. Habitat, fresh water, in boggy places, Ireland. Length of test about ·05 mm. (Plate 1, fig. F.)

Genera sometimes referred to the GROMIIDÆ: *Protogenes* (by Claus); *Lagynis* (by Carpenter).

EXPLANATION OF PLATE 1.

FIG.
A. *Lieberkuehnia Wageneri*, Clap. and Lachm. Magnified
B. *Mikrogromia socialis*, Archer sp. × 200.
C. *Gromia oviformis*, Dujardin. × 25.
D. *Diaphoropodon mobile*, Archer. × 100.
E. *Shepheardella tæniformis*, Siddall. Magnified.
F. *Amphitrema Wrightianum*, Archer. × 300.

PLATE 1.



FAMILY I. GROMIIDÆ.

CHAPTER VIII

THE FAMILY MILIOLIDÆ

THIS very important division comprises the whole of the porcellanous-shelled Foraminifera, and the tests are further distinguished by their imperforate shell-wall (sub-order *Imperforata vel Porcellanea*, Rupert Jones).

They are divided by H. B. Brady into six sub-families, more or less closely related to one another.

The characteristic features of the foraminiferal shell in the family MILIOLIDÆ are as follows :—

'Test imperforate ; normally calcareous and porcellaneous, sometimes encrusted with sand ; under starved conditions (*e.g.* in brackish water) becoming chitinous or chitino-arenaceous ; at abyssal depths occasionally consisting of a thin, homogeneous, imperforate, siliceous film' (H. B. Brady).

The shell wall of the miliolids is in nearly all cases of a smooth texture and usually chalk-white in appearance. In some examples, however, the surface is pitted, reticulated, or furrowed, whilst others have their surfaces encrusted with sand grains or shelly particles. Young specimens are, as a rule, translucent and opalescent. This latter appearance is a marked character with the group, for on mounting a fragment of almost any of the shells belonging to this family in a transparent medium, like Canada balsam, the white appearance gives place to a yellowish brown or horn colour, and the absence of the tiny tubules, which pierce the shell-wall of the hyaline forms, will be at once noticed.

In discussing the various members of this family it will presently be seen that this division of the Foraminifera exhibits a great many types of shell-building, and presents isomorphous analogues with those of the other groups of the arenaceous and the hyaline Foraminifera; and in fact are only distinguished from some other genera outside the family by the imperforate and porcellanous nature of the shell.

A certain degree of relationship with one another may be found amongst the various genera belonging to this family. The simplest types are those of the genera *Squamulina*, which has a single-chambered plano-convex test, and *Cornuspira*, which forms a non-septate tube coiled in one plane. Starting from *Squamulina*, a series of such chambers joined end to end gives rise to *Nodobacularia*; or, if non-septate and sending off radiating tubes, to a form like [illegible], an isomorph of the arenaceous genus *Astrorhiza*. In *Squamulina* again we may discover relationship with certain wild-growing *Miliolinæ* and also with the subspherical but septate *Nubecularia*.

In the Miliolidæ the fundamental form may be considered a globose segment, which afterwards, as by a modification of a spiral tube like *Cornuspira*.

develops a coiled series, as *Spiroloculina*, plano-spiral, but constricted and partially septate at either end of its axis of elongation. The next step is shown in *Miliolina* (*vera*), where the alternate series of partially divided segments are not disposed in one plane in their subspiral manner, but in the course of growth are turned on the longer axis of the shell three or five times in one complete revolution, as the case may be. An apparently simple form, *Biloculina*, which externally appears to be a series of chambers placed oppositely against the longer axis of the shell, is evidently derived from the milioline form, since, although its form A is constructed on this plan, form B, with the microspheric chamber, commences in many of the species, as Munier Chalmas and Schlumberger have shown, with a milioline form of shell of the quinqueloculine type—that is, having five chambers in one whorl—and only takes on the biloculine arrangement in the adult stage.

Labyrinthic modifications of the septate types of shell growth are often found among the Foraminifera, and *Fabularia* is an instance of such in the Miliolidæ. This genus resembles a *Biloculina* externally, but the chambers within are subdivided by meandering partitions of the secondary shell-growth.

The sub-families of the *Miliolinæ* and the *Peneroplidinæ* are connected by an annectent group, the *Haucrininæ*. The genera in this division resemble *Spiroloculinæ* in the earlier part of the shell, in being plano-spiral and septate, but they have their septa arranged without regard to any ratio with the whorls, and usually have more than two to each turn of the shell. The later growth of the shell is sometimes rectilinear, and, as in *Articulina*, may closely resemble the extended forms of *Nubecularia*.

Peneroplis may have its origin in a simple form, like *Cornuspira*, by its becoming septate. *Peneroplis* exhibits a spiral series of chambers the septa of which are numerously perforate, and the spiral manner often changes in later growth to an elongate straight series. The sub-genus *Archiacina* forms a link with genera having a cyclical arrangement of chambers by showing a tendency towards that plan of growth in the last formed portion of the adult shell.

Peneroplis passes into *Orbiculina* by the subdivision of its chambers into chamberlets by means of vertical partitions connecting septum with septum. The last-named spirally formed genus, again, forms a link with the discoidal shell of *Orbitolites*: this genus possesses a subglobular primordial chamber, and the succeeding chambers are distinctly spiral, but usually quickly assume a cyclical (concentric) manner of growth, although in one species at least a considerable part of the earlier shell is spiral. The annular chambers in *Orbitolites* are always subdivided into little subquadrate chamberlets, each with its stolon aperture for the passage of the sarcode into the neighbouring compartments. There are often two, three, or even more tiers of annuli superposed to form the entire shell, and these, in certain species, increase in number as the shell developes.

The relationship of the foregoing group to the *Alveolininæ* is easily recognised when we conceive the plan on which the test is formed. Like *Orbiculina* it is spiral, but instead of being compressed laterally, as in that genus, the shell is often enormously elongated on an axis passing through the umbilical centres.

The last sub-family of the *Keramosphærinæ* completes the series, in that it presents a modification of the *Orbitolites* type by the fact of its having the chamberlets arranged not in flat annuli, but in a sphæro-concentric manner.

Sub-family 1. NUBECULARIINÆ.

This group is distinguished by the irregular a-symmetrical form of the test, which is free or, perhaps more often, adherent; with a variable aperture or apertures, often rimmed in *Nubecularia* or otherwise thickened with extra shell growth.

GENUS *Squamulina*, SCHULTZE.

Test, a single inflated chamber, with aperture on the convex surface. *Recent.*

EXAMPLE.—*S. lævis*, Schultze, Organismus polythal., 1854, p. 56, pl. vi. figs. 16, 17.

Found by Schultze adhering to the surface of marine algæ from Ancona. Longest diameter of test, ·08 mm.

Some little doubt has been thrown on the validity of this genus as a separate type, some supposing it to be a young nubecularian. *Recent.* (Plate 2, fig. A.)

GENUS *Calcituba*, ROBOZ.

Test imperforate, normally adherent; consisting of a series of irregular and lengthened chambers more or less cylindrical, emanating from a central trunk-like segment; sometimes arranged radially, as in *Astrorhiza*. Apertures numerous at the terminals of the branches.

EXAMPLE.—*C. polymorpha*, Roboz, 'Sitz. Ak. Wiss. Wien,' vol. lxxxviii. 1883 (1884), p. 420, pl. —, figs. 1–16.

This, the only species of the genus, was discovered by Roboz, attached to algæ, in a marine aquarium in the Institute of Gratz, supplied by material from the Adriatic Sea.

The shape of the test in *Calcituba polymorpha* is extremely variable and irregular, and it starts from a young M[illegible]-like segment which eventually forms a kind of central core or trunk for the irregular offshoots of N[illegible]-like chambers. A section through the median plane of the test shows the chambers to be connected by a stoloniferous joint, made by the neck of one chamber being thrust, as it were, into the base of the succeeding chamber; in this latter feature, and also in the presence of numerous circular apertures to the offshoots of the test, this form shows a decided relationship morphologically speaking with the recent genus [illegible] (with an arenaceous test) and *Ramulina* (with a hyaline test). A typical specimen of *C. polymorpha* measures ·8 mm. in length. The lengths of the chambers in two separate individuals were ·242 mm. and ·269 mm. respectively, and their breadths ·128 mm. and ·095 mm.

This species is of especial interest on account of the valuable physiological researches conducted upon it by Schaudinn, in tracing the progressive changes in the division of the nucleus. The affinity of this genus is very closely connected with *Nubecularia* itself, especially in those irregular and inflated forms which have numerous apertures sporadically placed on the surface of the test, such as *Nubecularia Bradyi*, Millett, and *N. novorossica*, Karrer and Sinzow. *Recent.* (Plate 2, figs. B, C, D.)

GENUS *Nubecularia*, DEFRANCE.

Test spiral, straight, or irregular; usually adherent; septate. Surface often encrusted with sand.

The elongate adherent species are plentiful as fossils in certain Liassic and Oolitic deposits, and the coarse thick-walled forms constitute important calcareous strata in the Miocene sands of South Russia.

At the present day this genus is usually represented by species found almost restrictedly in the shallow-water sands of tropical or warm areas, and are rarely found in very deep water. *Carbo-Permian to Recent.*

EXAMPLES.—*N. lucifuga*, Defrance, 'Dict. Sci.

Nat.' vol. xxxv. 1825, p. 210; 'Atlas Zooph.' pl. xliv. fig. 3.

This species is generally found adherent, but sometimes free, and it is easily recognised by its spirally arranged chambers, which are very irregular in form compared with those of other species of this family. *N. lucifuga* is quite common in certain warm temperate areas, and is found in some abundance in the beach sands of Palermo, Melbourne, and off the coast of Tripoli. As a fossil it is known from Tertiary beds in France, and a variety was recorded by Howchin from the Carbo-Permian beds of Australia. *Carbo-Permian to Recent.* (Plate 2, figs. E and F.)

N. novorossica, var. *nodula*, Karrer and Sinzow, 'Sitz. k. Ak. Wiss. Wien,' vol. lxxiv. Abth. 1, 1876 (1877), p. 281, pl. —, figs. 11–25.

The species named above, of which the variety *nodula* is a many-apertured, agglomerated modification, is a thick-walled nubecularian in its typical form, but otherwise somewhat like *N. lucifuga* in contour. This and other varieties of *N. novorossica* occur in great abundance in the Sarmatian Sands (Miocene) of Kischenew, in Bessarabia. They average 3 to 4 mm. in diameter. The writer has described a modification of this form as occurring in the Upper Chalk of Taplow. *Upper Cretaceous, Miocene.* (Plate 2, fig. G.)

N. tibia, Jones and Parker, 'Quart. Journ. Geol. Soc.' vol. xvi. 1860, p. 455, pl. xx. figs. 48–51.

This species consists of an elongate series of ovate or pyriform chambers, and the test is either adherent or free. When attached, the form of the segments is plano-convex, but when free they assume a normal subcylindrical form. The commencement of this species often has an arrangement of chambers like that of *Miliolina*, by which it shows an affinity with *Articulina*.

By an error in determining its source *N. tibia* has often been quoted as a Triassic fossil. It first makes its appearance in the Lias, where it often occurs in company with *N. lucifuga*. In recent dredgings *N. tibia* is a shallow-water organism. *Lias*, *Oolite*, *Recent*. (Plate 2, fig. 4.) [1]

Sub-family 2. MILIOLININÆ.

Test coiled on an elongated axis, having two chambers in each complete whorl, either opposed and on a single plane of symmetry, or disposed at various angles round the longer axis. Aperture alternately, during growth, at either end of the shell.

GENUS *Biloculina*, D'ORBIGNY.

The chambers are arranged in a single plane, the last two only being visible. The internal structure of the microspheric form often has a quinqueloculine commencement. The aperture is usually crescentic, enclosing a valve-like projection, normally

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[1] **For references to other species of this genus and those that follow consult Sherborn's *Index to the Genera and Species of the Foraminifera*. Only one or two important types of each genus can be given here, on account of the limits of space.**

T[illegible] . the inner surface of the shell. Lias [illegible]

B. comata, [illegible] Brady, Rep. 'Chall.' vol. [illegible]

This is a pretty striated form of Biloculina, which was brought to light by the 'Porcupine' and 'Challenger' expeditions. It is rarely that we find [illegible] with a surface ornamentation so well marked as this, and the present species is also striking on account of its fairly large dimensions. It measures nearly 1 mm. in length. *B. comata* generally affects depths ranging from 300 to 600 fathoms. (Fig. [illegible] Plate 2. figs. I and J.)

B. [illegible] Lamarck sp. (*Miliolites ringens*). (Annales du Muséum, vol. v. 1804, p. 351, No. 1; 1807, vol. ix. pl. xvii. fig. 1.)

This is one of the earliest known species to such pioneers as Soldani, who in 1795 described it under the name of 'Frumentaria Ovula.' Lamarck, who adopted the Linnean system of nomenclature, gave it the name of *Miliolites ringens*, the generic name being used at the time equally for the biloculine, the triloculine, and the quinqueloculine types. *B. ringens* is a typical form of the genus, and exhibits a medium inflation of the chambers, *B. depressa* being narrower in section and *B. bulloides* more globose.

B. ringens makes its first appearance, so far as we know, in the Tertiary beds (Middle Eocene) of the Paris Basin, and it also occurs in strata of Miocene, Pliocene, and Pleistocene ages.

This species was met with in some abundance in the deep-water area of the northern part of the North Atlantic during the dredging operations by Professor Sars, who found the bottom temperature of the water nearly uniform, only varying from 32° F. to 34·9° F. between the depths of 300 and 2,000 fathoms. The mud from the bottom is a light-coloured ooze, and was called *Biloculina* mud, since it was supposed to be almost entirely formed of the tests of *Biloculinæ*. This does not seem to be the case, however, for it has been shown that after the fine silt was washed away the *Biloculinæ* only constituted 50 per cent. of the dried material.

Eocene to Recent. (Plate 2, figs. K and L.)

GENUS *Fabularia*, DEFRANCE.

The chambers are arranged in one plane, as in *Biloculina*, but the chamber cavities are subdivided or partitioned off into chamberlets and labyrinthulæ by shell projections and partitions, which results in the sarcode having to occupy numerous little channels throughout the shell, with perhaps the exception of the earlier chambers, as shown by Schlumberger in the case of the Miocene specimens. The aperture is porous or cribrate (sieve-like). *Lower and Middle Eocene and Miocene.*

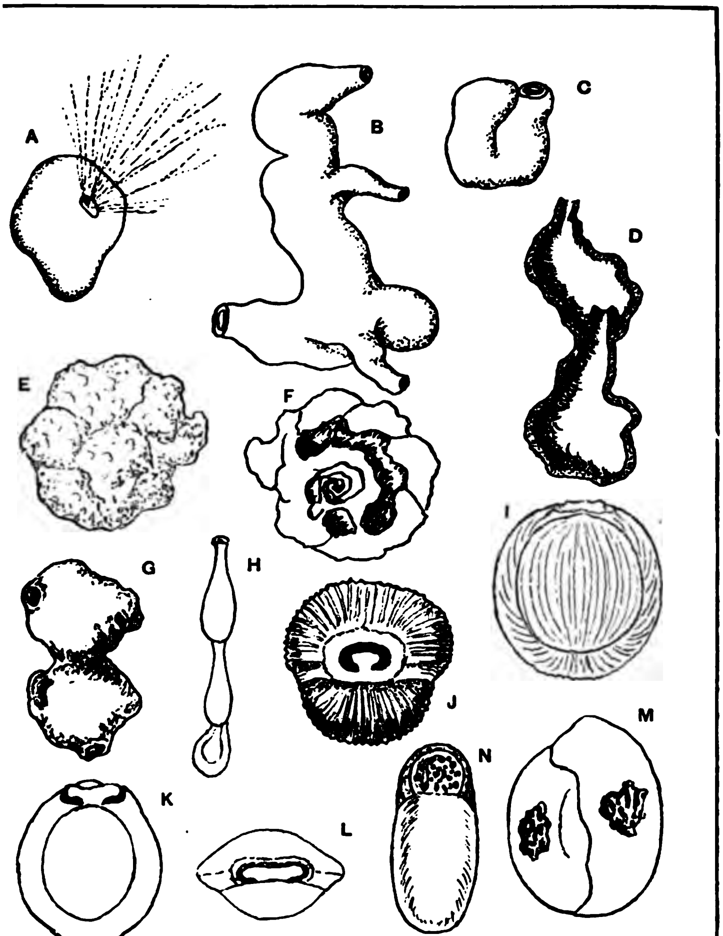
EXAMPLE.—*F. discolithus*, Defrance, 'Dict. Sci. Nat.' vol. xvi. 1820, p. 103; 'Atlas Zooph.' pl. xlviii. fig. 5.

The genus is very restricted in its range and is entirely fossil. It is best known by the above

EXPLANATION OF PLATE 2.

Fig.	
A.	*Squamulina lævis*, Schultze. Magnified.
B.	*Calcituba polymorpha*, Roboz. Typical specimen. × 50.
C.	*Calcituba polymorpha*, Roboz. Young shell. × 100.
D.	*Calcituba polymorpha*, Roboz. Medium section of the shell, passing through two chambers. × 150.
E.	*Nubecularia lucifuga*, Defrance (after Brady). A spiral form; superior aspect. × 10.
F.	*Nubecularia lucifuga*, Defrance. Inferior (attached) surface. × 10.
G.	*Nubecularia novorossica*, var. *nodula*, Karrer and Sinzow. × 5.
H.	*Nubecularia tibia*, Jones and Parker. Magnified.
I, J.	*Biloculina comata*, Brady. × 25.
K, L.	*Biloculina ringens*, Lamarck sp. (after Brady). × 13.
M, N.	*Fabularia discolithus*, Defrance (after Carpenter). × 5.

PLATE 2.



Family II. MILIOLIDÆ.

species, which is found in some frequency in the 'calcaire grossier' (Middle Eocene) of the Paris Basin. Externally *F. discolithus* resembles a laterally compressed *Biloculina* having a faintly striate surface, but the porous nature of the aperture reveals its internal labyrinthular or subdivided character. It often attains to a considerable size, sometimes as much as 6 mm. in length.

Two other species of *Fabularia* are known, one, closely related to the above form, *F. Zitteli* of Schwager, which was found in beds in Egypt of nearly similar age to those of the Paris Basin; and another lately described from the Miocene beds of Muddy Creek, Victoria, by Schlumberger, under the name of *F. Howchini*.

Middle Eocene. (Plate, figs. M and N.)

GENUS *Spiroloculina*, D'ORBIGNY.

The chambers in the shells of the genus *Spiroloculina* are arranged in a single plane, and the whole of them are visible on either side of the test. The aperture is generally circular with a toothed or T-shaped projection. Sometimes the aperture is prolonged into a neck or salient tube. This type is usually characteristic of shallow-water faunas, both in temperate and tropical areas, but one species, *S. tenuis*, is found at various depths down to 2,750 fathoms. *Carbo-Permian to Recent.*

EXAMPLES.—*S. asperula*, Karrer, 'Sitz. Ak. Wiss. Wien,' vol. lviii. Abth. 1, 1868, p. 136, pl. i. fig. 10.

This species has a thin complanate shell, and is encrusted with sand, which gives it a rough appearance, as its name implies. It was first described as occurring in the Miocene of Kostej, in the Banat, and it has since been found in the Folkestone-Gault. At the present day it occurs in shallow-water dredgings in the tropics. *Lower Lias to Recent.* (Plate 3, figs. A, *a*.)

S. planulata, Lamarck sp. (*Miliolites planulata*), 'Ann. Mus.' vol. v. 1805, p. 352, No. 4; 1822, 'Anim. sans Vert.' vol. vii. p. 613, No. 4.

The chief features of this form are a simple complanate and smooth-textured shell, with the surface of the chambers not thickened at the suture lines, as in some species, such as *S. limbata* and *S. impressa*.

S. planulata is commonest in shallow water, and as a fossil it seems to range from the *Carbo-Permian* onward, if its occurrence in Tasmanian rocks can be verified. (Plate 3, figs. B, *b*.)

GENUS MILIOLINA, WILLIAMSON.

Chambers inequilateral, coiled round the long axis of the shell, so that usually three or five are visible externally, but sometimes as many as eight. Aperture large and alternately occupying opposite extremities of the shell, generally furnished with a valve-like projection or tooth.

This important genus is usually well represented in shallow-water sands around the shore lines and coasts both of temperate and tropical countries, and the genus was one of the first to be noticed by the earliest workers on this group of animals. *Lias to Recent.*

EXAMPLES.—*M.* (*Adelosina*) *bicornis*, Walker and Jacob sp. (*Serpula bicornis*), Kanmacher's edition of Adams's 'Essays on the Microscope,' 1798, p. 633, pl. xiv. fig. 2.

A neat striate milioline form, fairly common in shallow-water deposits, and very rarely found deeper than 40 or 50 fathoms. It is a well-known British species. Schlumberger has shown that this species belongs to the type *Adelosina* of D'Orbigny, and that it has a distinct standing of its own in regard to the internal arrangement of the chambers—that is to say, in the dimorphic form B *Adelosina* has its megasphere completely enveloped by the first chamber, which becomes lenticular. It afterwards passes through the biloculine, triloculine, quadriloculine, and quinqueloculine stages.

M. bicornis occurs in the fossil condition in the Eocene of the Paris Basin and the London Clay, the Miocene of Vienna and Muddy Creek (Victoria), and in the Pliocene of Italy, St. Erth, and Suffolk. *Eocene to Recent.* (Plate 3, fig. C.)

M. oblonga, Montagu sp. (*Vermiculum oblongum*), 'Test. Brit.' 1803, p. 522, pl. xiv. fig. 9.

One of the commonest forms of the shallow-water *Miliolinæ*. It is distinguished by its lengthened test, the chambers of which are inflated and smooth. It exhibits sometimes three, sometimes five faces on the exterior of the shell. *M. oblonga* is found fossil in the Upper Chalk of Taplow, the London Clay, the

Miocene of Muddy Creek (Victoria), and the Pliocene of St. Erth, of Suffolk, and Italy. *Upper Cretaceous to Recent.* (Plate 3, fig. D.)

M. (*Quinqueloculina*) *seminulum*, Linné sp. (*Serpula seminulum*), 'Syst. Nat.' 1758, ed. x. p. 786; Gmelin's (xiii.) ed. 1788, pp. 37, 39.

This is one of the *Miliolinæ* which shows portions of five chambers on the surface of the shell (hence *Quinqueloculina*). It is generally looked upon as a central type of the group, and it is one of the most widely distributed of the family, both as to locality and depth; regarding the latter it is found down to 3,000 fathoms. *M. seminulum* was one of the earliest figured species of the genus, and was formerly described as a serpula, on account of its contorted and wormlike appearance, although, comparatively speaking, of very minute size. This species ranges as a fossil from the *Lower Eocene* upwards. (Plate 3, figs. E, *e*.)

The genera, or rather sub-genera, established by Munier Chalmas and Schlumberger by means of their work upon the internal appearance of the test in transverse section of the megalospheric form are as follows:—

Dillina, *Triloculina*, *Trillina*, *Quinqueloculina*, *Pentellina*, *Idalina*, *Adelosina*, *Periloculina*, *Massilina*, *Heterillina*, *Sigmoïlina*.

Thus, for example, *Massilina* is distinguished by having a quinqueloculine arrangement of chambers surrounding the megasphere, which are followed by a series of chambers disposed in one or two planes, as in a *Spiroloculina*, or two of the same intersecting in different planes.

In *Sigmoïlina* the chambers are arranged alternately at both poles of the megasphere, with a centrifugal or rotary twist of growth, so that a transverse section of the test shows the chambers grouped in sigmoidal fashion. Usually there is an extensive deposit of shell substance round each chamber-wall. (See Plate 3, figs. K, *k*.)

Sub-family 3. HAUERININÆ.

The test in this group is dimorphous—that is, exhibiting two different plans of growth at different stages of the shell-development. The chambers are partly milioline and partly spiral or rectilinear.

GENUS *Articulina*, D'ORBIGNY.

The shell commences with a milioline series of chambers, afterwards followed by a straight series. *Lower Eocene to Recent.*

EXAMPLE.—*A. Sagra*, D'Orbigny, De la Sagra's 'Hist. Physiq.' &c., Cuba, 1839, 'Foraminifères,' p. 183, pl. ix. figs. 23-26.

One of the interesting ornate forms, found chiefly in the vicinity of coral reefs, as in the West Indies and at the Fiji Islands. The early milioline chambers are clearly seen in this species; the aperture is a lengthened curved slit. *Recent.* (Plate 3, fig. F.)

EXPLANATION OF PLATE 3.

FIG.

A. *a.* *Spiroloculina asperula*, Karrer: *a.* peripheral aspect. × 45.

B. *a.* *Spiroloculina planulata*, Lamarck: *a.* oral aspect (after Brady). × 23.

C. *Miliolina* ([illegible]) *bicornis*, W. and J. sp. (after Brady.) × 25.

D. *Miliolina oblonga*, Montagu sp. (after Brady). × 35.

E. *a.* *Miliolina* ([illegible]) *seminulum*, Linné sp.: *a.* oral aspect (after Williamson). × 10.

F. *Articulina sagra*, D'Orbigny. × 50.

G. *Vertebralina striata*, D'Orbigny (after Brady). × 35.

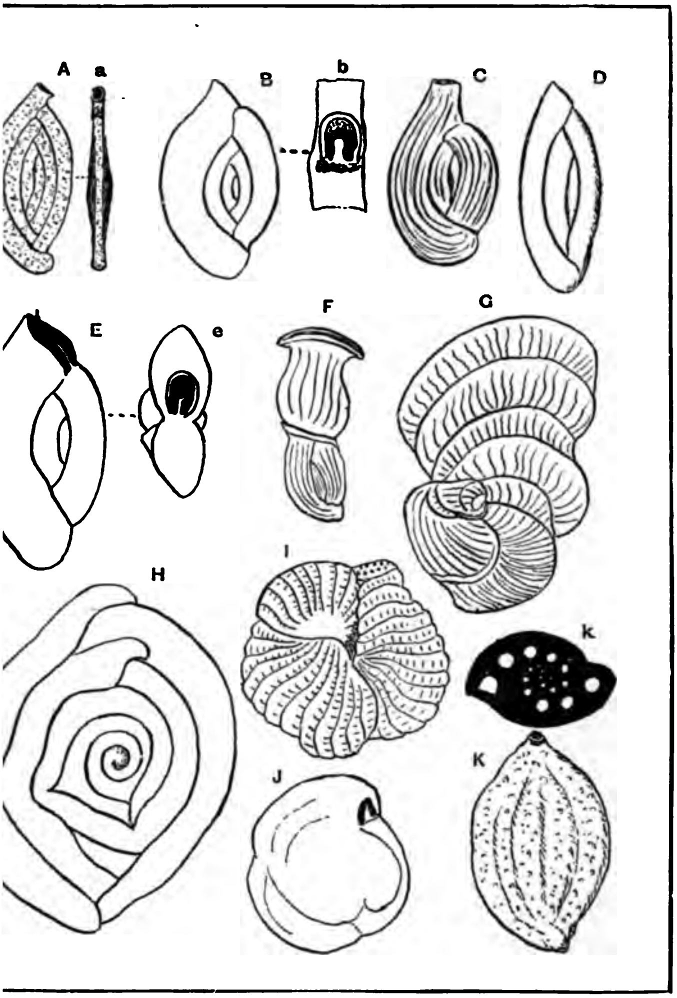
H. [illegible], Brady. × 50.

I. [illegible], Karrer (after Brady). × 35.

J. [illegible], D'Orbigny sp. (after Brady). × 10.

K. *a.* [illegible], Costa sp.: *b.* trans. section of test. (after Brady). × 30.

PLATE 3.



FAMILY II. MILIOLIDÆ (*continued*).

GENUS *Vertebralina*, D'ORBIGNY.

Early chambers partly milioline and partly planospiral, later segments in a straight series. *Eocene to Recent.*

EXAMPLE.—*V. striata*, D'Orbigny, 'Ann. Sci. Nat.' vol. vii. 1826, p. 283, No. 1; Modèle, No. 81.

The above species is often found in sponge sand from the Mediterranean, and it is frequent in shallow water round coral islands in the tropics.—*Recent.* (Plate 3, fig. G.)

GENUS *Ophthalmidium*, KÜBLER.

Spiral and unconstricted at the commencement, subsequently with two or more segments in each whorl. *Lias to Recent.*

EXAMPLE.—*O. tumidulum*, Brady, 'Rep. "Chall."' vol. ix. 1884, p. 189, pl. xii. fig. 6.

This species was obtained by H.M.S. 'Challenger' from the West Indies at a depth of 390 fathoms. An arenaceous isomorph of this form was found by the writer in the Gault clay at Folkestone.—*Recent.* (Plate 3, fig. H.)

GENUS *Hauerina*, D'ORBIGNY.

Commencing with a *miliolina*-like series, afterwards planospiral, with more than two segments in each whorl. *Cretaceous to Recent.*

EXAMPLE.—*H. ornatissima*, Karrer sp. (*Quinqueloculina ornatissima*), 'Sitzungsb. Ak Wiss. Wien,' vol. lviii. 1868, p. 151, pl. iii. fig. 2.

This elegant little species was first described as a fossil from the Miocene of the Banat. It is a well-known form in the coral sands of tropical areas; for example, it is common at Funafuti, in the Pacific, at depths ranging from 35 to 150 fathoms, whilst at less depths it seems to be rare. *Miocene and Recent.* (Plate 3, fig. I.)

GENUS *Planispirina*, SEGUENZA.

Chambers equitant, otherwise arranged as in *Hauerina*; the lateral alar prolongations of the latest convolution enclosing the previous whorl. *Tertiary to Recent.*

EXAMPLE.—*P. contraria*, D'Orbigny sp. (*Biloculina contraria*), 'Foram. Fossiles de Vienne,' 1846, p. 266, pl. xvi. figs. 4–6.

In the earlier part of the shell there are two chambers in each whorl, which increase later to five or six. The walls of the chambers extend over the lateral faces of the shell, as in the nummulite. For this reason Steinmann proposed the name *Nummoloculina* for the genus, which, however, does not stand, since Seguenza's name is of earlier date. The range of this species is from the *Miocene to Recent.* (Plate 3, fig. J.)

Sub-family 4. PENEROPLIDINÆ.

The test in this group is planospiral, or cyclical, sometimes crozier-shaped, and bilaterally symmetrical.

GENUS *Cornuspira*, SCHULTZE.

Consists of a planospiral tube, which is univided.

This genus is isomorphous with certain species of he arenaceous genus *Ammodiscus* and the hyaline enus *Spirillina*.

Cornuspira has been doubtfully recorded from the arbo-Permian of Tasmania. The recorded occurences of the genus from Jurassic and Cretaceous ocks are not satisfactory, for the specimens geneally prove to be *Ammodisci* on minute examination. he genus is common, however, throughout *Tertiary* ossiliferous strata to recent times.

EXAMPLE.—*C. involvens*, Reuss, 'Sitz. k. Ak. Wiss. Vien,' vol. xlviii. (Abth. 1), 1863 (1864), p. 39, pl. i. g. 2.

This species is distinguished by the embracing haracter of the whorls as they rest successively on ach in turn, as well as in the roundness of the tube. n this latter feature it differs from *C. foliacea*, which as a thin flattened shell. It is usually a shallowater form, but is sometimes found at considerable epths. *Tertiary to Recent.* (Plate 4, fig. A.)

GENUS *Peneroplis*, MONTFORT.

Chambers undivided; arrangement either planoiral throughout or spiral only at the commenceent, subsequently becoming rectilinear or cyclical. *ertiary to Recent.*

EXAMPLES.—*P. arietinus*, Batsch sp. (*Nautilus*—

Lituus—arietinus), 'Conch. Seesandes,' 1791, pl. vi. fig. 15, *c* (type).

This is a common form in the sand from the shores of the Levant, and can often be obtained from sponges. This and other forms of the genus are so nearly related that they are by some authors grouped as a species under the collective type-name *P. pertusus*. The genus is commonly found at depths of less than 30 fathoms. *Recent.* (Pl. 4, figs. B, *b*.)

P. planatus, Fichtel and Moll sp. (*Nautilus planatus*), 'Test. Micr.' 1798, p. 91, pl. xvi. fig. 1, *d*, *e*, *f*.

A broad complanate form with a striated surface. The apertures are a single row of pores on the septal face. *Recent.* (Plate 4, fig. C.)

The sub-generic types which call for special notice are *Archiacina*, Munier Chalmas, in which the test is of the *P. planatus* type, but the later chambers tend to a cyclical arrangement; and *Monalysidium*, Chapman, which includes the delicate-shelled forms, such as those of the *P. lituus* type, and the recent form *M.* [illegible] *Sollasi*. (Plate 4, fig. D.)

GENUS O[illegible], LAMARCK.

Chambers subdivided by transverse secondary septa, [illegible] segments [illegible]: arrangement either planospiral throughout or partly cyclical: contour nautiloid [illegible] -shaped or complanate.

EXAMPLE.—[illegible] Fichtel and Moll sp.

(*Nautilus*), 'Test. Micr.' 1798, pp. 112, 113, 115, pls. xxi.-xxiii.

The single species of this genus is found commonly in the West Indies, the Red Sea, and the Indian Ocean. It is found at moderate depths. *Miocene to Recent.* (Plate 4, figs. E, *e.*)

The sub-generic type *Meandropsina* (Munier Chalmas) has a test in which the median layer of chamberlets is arranged as in *Orbiculina*, whilst the outer layers are formed on the plan of *Orbitolites.*

GENUS *Orbitolites*, LAMARCK.

Test discoidal, sometimes undulate or rarely sinuous; growth either spiral (non-embracing) just at the commencement, or with one or more inflated primordial chambers; subsequently cyclical; chambers more or less regularly divided into chamberlets. *Upper Cretaceous to Recent.*

EXAMPLE.—*O. complanata*, Lamarck, 'Syst. Anim. sans Vert.' p. 376; Carpenter, 'Phil. Trans.' 1856, p. 224, pls. iv.-ix.

This is one of the best known species of Foraminifera, for they form a large proportion of the calcareous sands which make the beaches, and assist in the building up of the coral islands of the Pacific and Indian Oceans. It is common in all tropical and temperate seas, occurring abundantly in the shallow-water sands.

O. complanata is the most complex species of the genus, and in adult forms is composed of many superposed layers of chamberlets, the number of the layers increasing as the shell advances in growth. Sometimes this species loses its regularly discoidal contour and, growing attached to algæ and other marine objects, becomes more or less sinuous and irregular.

Owing to the thinness of the wall of the primordial segment, and to the fact that it usually protrudes beyond the general surface of the test, the specimens found in shore sands, where they are exposed to weather action, are often found perforated in the middle. The natives of coral islands often take advantage of this, and select the larger specimens (often half an inch or more across) to sew into the native dresses for decorative purposes.

There is a large variety of *O. complanata* known as variety *plicata* (Dana), or variety *laciniata* (Brady), in which the edge of the disc is double and is also frilled. This condition of the shell was shown by H. B. Brady and other observers to contain the megalospheric young of the species, enclosed in large chamberlets arranged around the periphery. This particular variety is only found in tropical areas, and usually in the neighbourhood of coral reefs, in quite shallow water.

O. complanata apparently first appeared in the Maestricht beds (Upper Cretaceous), and continued on to the present day. (Plate 4, figs. F, *f*.)

Sub-family 5. ALVEOLININÆ.

Test spiral, elongated in the line of the axis of convolution, chambers divided into chamberlets.

GENUS *Alveolina*, DEFRANCE.

Test subglobular, elliptical, or fusiform; recent species often with subdivided chamberlets. *Cretaceous to Recent.*

EXAMPLE.—*A. Boscii*, Defrance sp. (*Oryzaria*), 'Dict. Sci. Nat.' vol. xvi. 1820, p. 104.

The chamberlets in this species are often subdivided by horizontal partitions, which give rise to a complex series of pores, appearing externally along the septal plane of the test. This species seems restricted to shallow water, being rarely found deeper than 30 fathoms. *Middle Eocene to Recent.* (Plate 4, figs. G, *g*.)

The sub-genus *Flosculina*, Stache, is chiefly distinguished by its extraordinarily thickened shell-wall, the rows of chamberlets occupying a proportionately small space.

GENUS *Lacazina*, SCHLUMBERGER.

Test ovoid or subspherical; the chambers arranged in an elongated coil, as in *Alveolina*, but having apertural communication alternately at opposite ends. The chambers are subdivided into chamberlets. *Cretaceous and Tertiary.*

EXAMPLE.—*L. Wichmanni*, Schlumberger, 'Bull.

EXPLANATION OF PLATE 4.

FIG.

A. *Cornuspira involvens*, Reuss. × 30.

B, *b*. *Peneroplis arietinus*, Batsch sp.: *b*, oral aspect. × 20.

C. *Peneroplis planatus*, F. and M. sp. × 20.

D. *Peneroplis* (*Monalysidium*) *Sollasi*, Chapman. × 50.

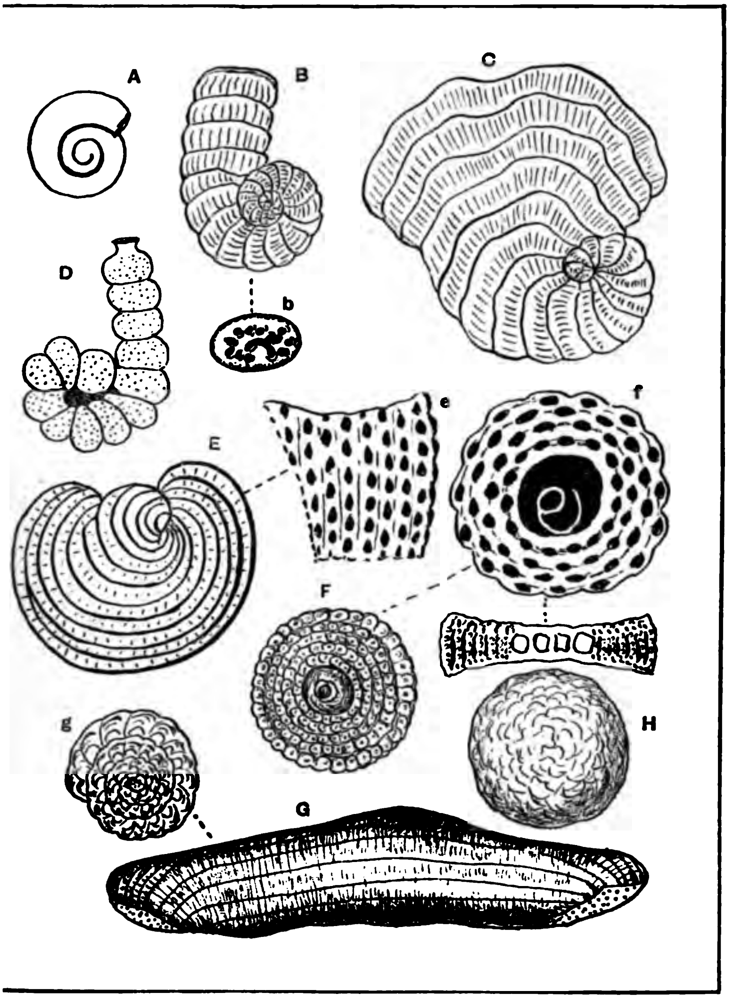
E, *c*. *Orbiculina adunca*, F. and M. sp.: *e*, half-section of a fragment of test showing chamberlets. E × 13, *c* × 32.

F, *f*. *Orbitolites complanata*, Lam. (young specimens): *f*, transverse and vertical sections (after Carpenter). F × 30, *f* × 36.

G, *g*. *Alveolina Boscii*, Defr. sp.: *g*, transverse section (after Brady). × 15.

H. *Keramosphæra Murrayi*, Brady. × 7.

PLATE 4.



Family II. MILIOLIDÆ (*concluded*).

Soc. Géol. France,' ser. 3, vol. xxii. 1894, p. 296, pl. xii. and text figure 1.

The test in this species resembles *Alveolina sphærica*, but with the internal arrangement of chambers peculiar to *Lacazina*. The chamberlets are small, with much secondary shell growth, as in *Flosculina*. Surface of the test pitted. *Tertiary*, New Guinea.

Sub-family 6. KERAMOSPHÆRINÆ.

Test spherical, chambers in concentric layers.

GENUS *Keramosphæra*, BRADY.

Test spherical, composed of a multitude of more or less irregularly shaped chamberlets arranged in concentric layers. This form appears to be isomorphous with the hyaline *Gypsina globulus*.

EXAMPLE.—*K. Murrayi*, Brady, 'Ann. and Mag. Nat. Hist.' ser. 5, vol. x. 1882, p. 242, pl. xiii.

In transverse section the test appears somewhat like that of *Orbitolites* in its arrangement of the chamberlets, but it is more irregular, and the pores on the surface communicate with each chamberlet obliquely instead of by pores disposed normally to the surface of the test, as in *Orbitolites*.

Only two specimens of this interesting porcellanous type were found by Mr. (now Sir John) Murray during the 'Challenger' expedition. They came from the deposit of Diatom Ooze, at some distance off the S.W. of Australia, from a depth of 1,950 fathoms. *Recent*. (Plate 4, fig. H.)

CHAPTER IX

THE FAMILY ASTRORHIZIDÆ

General Characters and Affinities.—Test invariably composite, usually of large size and monothalamous; often branched or radiate, sometimes segmented by constriction of the walls, but seldom or never truly septate; polythalamous forms rarely symmetrical.

The various genera of this group are all arenaceous in their shell structure; and this series, together with the succeeding family of the Lituolidæ and the portion of the family Textulariidæ consisting of the arenaceous types, form the comprehensive group of the Arenacea of Rupert Jones and the 'kieselschalige Foraminiferen' of Von Reuss. The material of which the test is composed comprises coarse or fine sand-grains (quartzose), fine arenaceous mud, admixtures of calcareous mud and sand, sponge spicules felted together or made coherent by sarcodic cement, the agglomerated tests of other Foraminifera, or, in rare cases, merely of an investment of chitinous substance with or without a meagre stiffening of fine sand.

The majority of the forms which are comprised in the Family Astrorhizidæ, owing to their generally deep-water habits, have been discovered only of late years, comparatively speaking, by the modern methods of deep-sea dredging, the operations of which have effectually proved that almost every part of the ocean floor is the habitat of living organisms.

One of the most noteworthy forms in this family is that of the genus *Astrorhiza*, which, as a central type, has been taken by Brady to indicate the general character of the whole group. A shallow-water species of this genus was discovered as far back as 1857 by Sandahl, who found his specimens of *A. limicola*, as the species is named, off the coast of Sweden. This is, however, one of the exceptions, since the majority are found in deep water, and to this exceptional occurrence the early discovery of the genus is due.

The Astrorhizids are for the most part irregular in form, or at all events do not show the same symmetry as members of other families of the Foraminifera. A special feature in the construction of the test is that, notwithstanding the rough exterior, the inside is, wé may say, invariably smooth, and often quite glazed or polished with the sarcodic or chitinous cement; reminding one in this respect of the internal surface of molluscan shells where in contact with the mantle of the animal.

The genus *Psammosphæra* is one of the simplest types of the ASTRORHIZIDÆ, consisting of a single globular segment enclosed in a rough sandy test, without any definite aperture, for the sarcode flows out between the interstices of the coarse sand-grains which form the investment.

An agglomerated series of spherical or sub-spherical chambers results in a form like the genus *Sorosphæra*. In *Saccammina* the walls of the test are more firmly cemented, and a distinct orifice is present. In the fossil species, found in the Carboniferous limestone (*S. fusuliniformis*), the shell-wall is partly arenaceous and partly calcareous; or, perhaps more correctly, consists of calcareous grains with a partially calcareous cement (subarenaceous); and there is a tendency for the subglobular or fusiform segments to form a connected series of chambers united by a short stolon or necklike prolongation, instead of breaking off as a separate individual after reproduction, as in the recent *S. sphærica*. On the other hand the recent *S. socialis* shows some affinity towards the fossil form in its tendency to assume a lateral plan of serial budding, the segments being formed side by side, with their apertures directed outwards.

Other similarly rudimentary types have their tests composed of sponge spicules selected by the organism from the surrounding mud; these may be more or less closely felted together, and mingled in some cases with a small proportion of the mud. These spicular forms are chiefly found in the sub-family PILULININÆ.

The tubular modifications of the ASTRORHIZIDÆ frequently consist of a simple tube with constrictions, but with one end closed, as in *Jaculella* and *Hyperammina*, whilst some sinuous and branching forms are represented by *Rhizammina*.

The typical *Astrorhiza* has a test composed of fine sand and mud; the primordial portion of the test is the central swollen part, from which starts a series of radiating tubes. Modifications of this type form are found in *Dendrophrya*, the tubes of which are usually compressed and irregular.

Syringammina is a complicated radial growth of astrorhizid tubes, the whole test having a spherical contour.

A ramifying network of finely arenaceous tubes adherent to shells and algæ is represented in the genus *Sagenina*. In *Rhabdammina* the test is tubular and radial, the arms being limited in number to three, four, or five rays, which are generally straight. The structure of the test is usually coarsely arenaceous. *Marsipella* is another tubular form, with apertures at both ends; and its test is normally composed of short sponge spicules, grouped in little bunches as it were side by side.

Botellina is distinguished from some forms of *Hyperammina* having regular or straight tubes, by the peculiar inner structure of the test, which in the former genus is irregularly divided by partitions, so that the interior is labyrinthic.

The recent genus *Aschemonella* is singular in having a somewhat different structure from the rest of the ASTRORHIZIDÆ, for in this genus we have indications of a partially septate test, connecting it with the unsymmetrical forms of the Porcellanous and Hyaline groups, as *Nubecularia* and *Ramulina*. In external characters it also bears some resemblance to the fossil genera *Stacheia* and *Nodosinella*, but differs in its simple chamber cavities and thinner shell-walls.

Haliphysema is another example of the types which construct their tests largely of sponge spicules. The bristling termination of the test causes the organism to look very like a tiny sponge; and it was, indeed, taken for such by Bowerbank, who first described it as the smallest known British sponge.

Some doubt has been expressed regarding the validity of some of the more irregular of the foregoing examples of arenaceous organisms as definite rhizopod structures, and Professor Haeckel is disposed to regard them as members of the group of deep-sea keratose sponges (*Ammoconidæ*). In point of size, for instance, these arenaceous forms greatly differ from the Keratosa, being much smaller, even when fully developed.

The true forms of arenaceous Foraminifera are practically unknown to us from the oldest rocks, and there is, therefore, no direct evidence that these were the primitive forms of foraminiferal life, although strongly maintained by some writers. The oldest Foraminifera known to us, as will be seen in the chapter on the Geological Range of these organisms, are those of the hyaline group. This is to be expected as a natural sequence in their relations to the evolution of marine deposits and their accompanying faunas; for it has been shown, by Murray and others, that the mud line round continents is the great feeding-ground of the various groups of animal life, and, with equal reasoning, the starting-point of many types of life, which subsequently became modified by change of condition, such as the abyssal for example, which, according to its faunas, may be regarded as abnormal, since at the present time only erratic or specialised modifications of life are found there. At first thought it might seem that the simplest type of test structure would be the arenaceous tube or sphere, but observations in other groups will serve to show how a decidedly complex structure may be produced on the simplest possible plan. Looking further into the case of the foraminiferal shell, the essential feature of the animal is its ability to send forth reticulate and threadlike pseudopodia. These extruded threads become, in the course of the building up or formation of the shell-wall, partially surrounded by shell-substance along a certain line external to the main body or series of segments, and thus, by a simple process of calcification of the external layer, or deposition at the bases of the pseudopods, an apparently complex shell-structure may be formed, corresponding with any of the hyaline types which have been found in the lower palæozoic rocks.

Sub-family 1. ASTRORHIZINÆ.

Walls thick, composed of loose sand or mud, very slightly cemented.

GENUS *Astrorhiza*, SANDAHL.

Test fusiform or depressed; in the latter case either sublenticular, with angular or irregularly radiate margin, or in branching masses. Apertures terminal in each ray or branch. *Recent*.

EXAMPLE.—*A. arenaria*, Norman, 'Proc. Roy. Soc.' vol. xxv. 1876, p. 213; Brady, 'Rep. "Chall."' vol. ix. 1884, p. 232, pl. xix. figs. 5–10.

This is a deep-water form, being seldom found in less than 150 fathoms, and usually much more. It is almost essentially a North Atlantic species. Norman obtained it from Norway, Goës from Spitzbergen, and Brady from the Cape of Good Hope (a single example). *Recent*. (Plate 5, fig. A.)

GENUS *Pelosina*, BRADY.

Test formed of mud, with a chitinous lining; more or less flask-shaped or subcylindrical. *Recent*.

EXAMPLE.—*P. rotundata*, Brady, 'Quart. Journ. Micr. Sci.' vol. xix. 1879, p. 31, pl. iii. figs. 4 and 5.

The walls of this species are very thick and composed of soft mud or ooze. Its range in depth appears to be from 640 to 2,050 fathoms. *Recent*. (Plate 5, fig. B.)

GENUS *Storthosphæra*, SCHULZE.

Test subglobular, very irregular externally; apertures numerous, situated in horn-like protuberances; interior smooth.

EXAMPLE.—*S. albida*, Schulze, 'II. Jahresberichte d. komm. Untersuch. d. deutsch. Meere,' Berlin, 1874, p. 113, pl. ii. figs. 9*a–d*.

This genus is represented by a single species only, which until lately seemed to be restricted in its habitat to the N. Atlantic, where it was found off the coast of Norway, the Faröe Channel, and the Bay of Biscay, all in moderately deep water. A doubtful worn example was obtained from the S. Atlantic in 1,900 fathoms by the 'Challenger.' Dr. Flint records it from the Gulf of Mexico at 730 fathoms ('Albatross' Collection), and it has also been found by Dr. Egger in the 'Gazelle' dredgings off Western Australia. *Recent.* (Plate 5, fig. C.)

GENUS *Dendrophrya*, STRETHILL WRIGHT.

Test adherent, formed of mud with a chitinous basis; either irregularly outspread or columnar and branching. *Post-Tertiary. Recent.*

EXAMPLE.—*D. radiata*, Str. Wright, 'Ann. and Mag. Nat. Hist.' ser. 3, vol. viii. 1861, p. 122; Brady, 'Rep. "Chall."' vol. ix. 1884, p. 238, pl. xxvi. A, figs. 10–12.

This shallow-water form is allied in structure to *Astrorhiza*, but the test is very variable in form. It was found by the above author in the Old Granton Quarry, near Edinburgh, and in the low-tide pools of Cumbrae, Firth of Clyde, generally attached to stones and fuci. The other remaining species of this genus, *D. erecta*, has been recorded by the author from the Post-Tertiary deposits of Barry Dock, Cardiff. *Recent.* (Plate 5, fig. D.)

GENUS *Syringammina*, BRADY.

Test consisting of a large rounded mass of branching radiating tubes, arranged in more or less distinct layers or tiers; texture coarsely arenaceous, the sand-grains very loosely aggregated. *Recent.*

EXAMPLE.—*S. fragilissima*, Brady, 'Proc. Roy. Soc.' vol. xxxv. 1883, p. 155, pls. ii. and iii.

This is a peculiar organism, resembling a mass of *Astrorhiza*-like tubes arranged radially. When broken open the separate tubes are seen to bear numerous apertures opening into the interstices of the mass. The examples on which the description is based were obtained from the 'Triton' dredgings in the Faröe Channel by Murray. The specimens measure about 1½ inch (38 mm.) in diameter. *Recent.* (Plate 5, figs. E, *e*.)

Sub-family 2. PILULININÆ.

Test monothalamous; walls thick, composed chiefly of felted sponge spicules and fine sand, without calcareous or other cement.

GENUS *Pilulina*, CARPENTER.

Test nearly spherical; aperture a long and more or less curved or sigmoid slit. *Recent.*

EXAMPLE.—*P. Jeffreysii*, Carpenter, 'The Microscope,' 5th ed. 1875, p. 532, figs. *d*, *e*.

This is the only species of the above genus, and until lately examples were only known from the 'Porcupine' dredgings, from the N. Atlantic, at 630–1,476 fathoms.' It has again been recorded quite lately by Flint from the N. Atlantic ('Albatross' Collection). *Recent.* (Plate 5, fig. F.)

GENUS *Technitella*, NORMAN.

Test oval or subcylindrical; aperture, typically, a rounded orifice at one end. *Recent.*

EXAMPLE.—*T. legumen*, Norman, 'Ann. and Mag. Nat. Hist.' ser. 5, vol. i. 1878, p. 279, pl. xvi. figs. 3, 4.

A variable species, but distinguished by its elongate-oval form. It is sometimes quite encrusted with mud, but on removing this the characteristic spicular test is seen beneath. The range in depth of this form is very great—from 60 to 2,350 fathoms—and it is found in almost every part of the world, though never very common in any sounding. *Recent.* (Plate 5, fig. G.)

GENUS *Rhaphidoscene*, VAUGHAN JENNINGS.

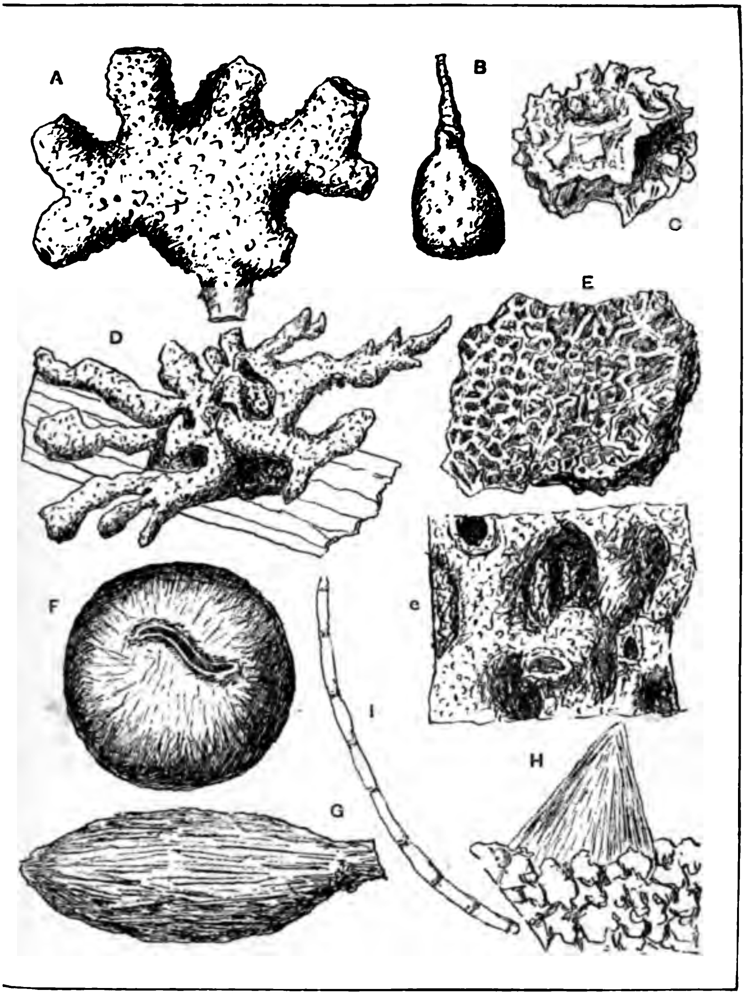
Test conical or tent-shaped, composed of sponge spicules; adherent. Aperture probably at the apex. *Recent.*

EXPLANATION OF PLATE 5.

FIG.

A. *Astrorhiza arenaria*, Norman (after Goës). × 5.
B. *Pelosina rotundata*, Brady. × 10.
C. *Storthosphæra albida*, Schulze (after Brady). × 10.
D. *Dendrophrya radiata*, Strethill Wright (after Brady). × 30.
E, *e*. *Syringammina fragilissima*, Brady. E = nat. size; *e* = × 8.
F. *Pilulina Jeffreysii*, Carpenter. × 8.
G. *Technitella legumen*, Norman (after Brady). × 35.
H. *Rhaphidoscene conica*, Jennings. × 18.
I. *Bathysiphon filiformis*, M. Sars. × 3.

PLATE 5.



Family III. ASTRORHIZIDÆ.

EXAMPLE.—*R. conica*, Jennings, 'Journ. Linn. Soc., Zool.' vol. xxv. 1895, p. 320, pl. x.

Test conical, height slightly greater than width at the base. Composed of spicules closely arranged, and pointing from the base to the apex. Base of test attached by a small amount of whitish, possibly calcareous, cement. Adherent on *Botellina* tests. Height about 1 mm. From the Faröe Channel at 440 fathoms. *Recent.* (Plate 5, fig. H.)

GENUS *Bathysiphon*, SARS.

Test long, cylindrical, slightly tapering; in the form of a straight or curved tube open at both ends.

EXAMPLE.—*B. filiformis*, G. O. Sars, 'Vidensk.-Selsk. Forhandl.' 1871, p. 251; Brady, 'Rep. "Chall."' vol. ix. 1884, p. 248, pl. xxvi. figs. 15-20.

This species has a very long and narrow tube, often two inches in length. The walls of the test are composed of felted spicules and fine sand. Colour light grey or white; sometimes yellowish brown. In the living state the shell is filled with dark-coloured or nearly black sarcode.

It is a rare form, and has been recorded from the Hardanger Fiord (M. Sars, G. O. Sars, Norman), Bay of Biscay (Norman, De Folin), Amboyna (Brady), Arabian Sea (Chapman). *Recent.* (Plate 5, fig. I.)

Sub-family 3. SACCAMMININÆ.

Chambers nearly spherical; walls thin, composed of firmly cemented sand-grains.

GENUS *Psammosphæra*, SCHULZE.

Test a single globular chamber without any general aperture, the pseudopodia issuing from interstitial orifices. *Jurassic to Recent.*

EXAMPLE.—*P. fusca*, Schulze, 'II. Jahresberichte d. komm. Untersuch. d. Deutsch. Meere,' p. 113, pl. ii. fig. 8, *a, f*.

This little spherical foraminifer is normally free, but is sometimes found attached to stones, or built round sponge spicules. It is widely distributed, both geographically and bathymetrically. It has also been recorded as fossil from the Upper Jurassic of Switzerland, by Haeusler. *Upper Jurassic and Recent.* (Plate 6, fig. A.)

GENUS *Sorosphæra*, BRADY.

A number of gobular chambers adherent to each other, without distinct stoloniferous tubes and with no general aperture. *Recent.*

EXAMPLE.—*S. confusa*, Brady, 'Quart. Journ. Micr. Sci.' vol. xxi. N.S. 1879, p. 98, pl. iv. figs. 18, 19.

The walls of this species are thin and finely arenaceous in texture, with minute interstitial orifices. Diameter of the colony sometimes one-sixth inch (4·5 mm.) It has been found in various parts of the N. Atlantic from 542 to 900 fathoms, and in the N. Pacific at 2,900 fathoms. *Recent.* (Plate 6, fig. B.)

Genus *Saccammina*, M. Sars.

One or several gobular, pyriform, or fusiform chambers, with distinct apertures. Polythalamous forms with or without stoloniferous connections. *Carboniferous and Recent.*

Examples.—*S. fusuliniformis*, M'Coy sp. (=*S. Carteri*, Brady) [*Nodosaria fusulinaformis*], 'Ann. and Mag. Nat. Hist.' ser. 2, vol. iii. 1849, pp. 131, 132. Chapman, *ibid.*, ser. 7, vol. i. 1898, p. 215, woodcut.

This is an important rock-forming organism, since it often constitutes a large proportion of the limestones of the Carboniferous formation. The weathered spherical tests stand out in relief on the rock, and the limestone containing them is called 'the spotted post' by the Cumbrian miners. The subspherical tests of *S. fusuliniformis* are usually found separated, but such was not their condition during growth, for when their remains are found protected, as, for example, enclosed in the shell of *Euomphalus*, we find the chambers are united in a straight or slightly curved series, and, indeed, even in the rock itself we may often see two or even three chambers connected together. *Carboniferous Limestone.* (Plate 6, fig. C.)

S. sphærica, M. Sars, 'Vidensk.-Selsk. Forhandl.' 1868, p. 248; Brady, 'Rep. "Chall."' vol. ix. 1884, p. 253, pl. xviii. figs. 11–17.

The globular or pyriform tests of this species are composed of coarse arenaceous material. The sand forming the walls is generally quartzose; that of the fossil species seems to have been calcareous. *S. sphaerica* is dredged up in considerable numbers from some localities; in this it resembles the occurrence of the fossil species. *Recent.* (Plate 6, fig. D.)

Sub-family RHABDAMMININÆ.

Test composed of firmly cemented sand-grains, often with sponge spicules intermixed; tubular, straight, radiate, branched, or irregular; free or adherent; with one, two, or more apertures; rarely segmented.

GENUS *Jaculella*, BRADY.

Test elongate, tapering; aperture at the broad end. *Recent.*

EXAMPLE.—*J. acuta* Brady, Quart. Journ. Micr. Sci. vol. xix, N.S. 1879, p. 35, pl. iii, figs. 12, 13.

In this species the test is elongate, closed and pointed at one end, gradually increasing in width towards the other. The walls are coarsely arenaceous. Length [illegible] to [illegible] inch or even more. It has a wide geographical distribution. *Recent.* (Plate 6, fig. E.)

GENUS *Hyperammina*, BRADY.

Test elongate, tubular, the closed end broad and rounded, sometimes inflated, so as to form a distinct chamber; tube straight or branched, free or adherent. *Silurian to Recent.*

EXAMPLE.—*H. elongata* Brady, Quart. Journ. Micr. Sci. vol. xix, N.S. 1879, p. 33, pl. iii, fig. 3.

Test with a spherical or oval primordial chamber, opening into a long tortuous tube, the whole often adherent to the surfaces of shells or stones. Shell-wall thin and finely arenaceous. Diameter of tube ·05 to ·2 mm. There is no real evidence to establish the identity of *Girvanella* with the above form; it is more than likely that the Girvan fossils are a form of the tortuous algoid bodies common in certain palæozoic and mesozoic limestones. *Jurassic to Recent.* (Plate 6, fig. F.)

GENUS *Marsipella*, NORMAN.

Test fusiform or cylindrical, with an aperture at each end; largely composed of sponge spicules, especially near the extremities. *Jurassic and Recent.*

EXAMPLE.—*M. cylindrica*, Brady, 'Proc. Roy. Soc. Edinb.' 1882, vol. xi. p. 714; 'Rep. "Chall."' vol. ix. 1884, p. 265, pl. xxiv. figs. 20–22.

This form has a delicate spicular test. It is widely distributed, and ranges in depth from 210 to 1,900 fathoms. *Recent.* (Plate 6, fig. G.)

GENUS *Rhabdammina*, M. SARS.

Test rectilinear, radiate, or irregularly branching; with or without a central chamber. The open ends of the tubes forming the apertures. (?) *Lower Pliocene to Recent.*

EXAMPLE.—*R. abyssorum*, M. Sars, 'Vidensk.-Selsk. Forhandl.' 1868, p. 268; Brady, 'Rep. "Chall."' vol. ix. 1884, p. 266, pl. xxi. figs. 1–13.

The original specimens were dredged in deep water off the coast of Norway by Professor M. Sars. They are frequent in many of the deep-sea soundings from all parts of the world, occurring in both low and high latitudes.

This species is typically triradiate, but occasionally varies in having four or even five arms to the test. The shell wall is coarsely sandy, and there is a fairly large proportion of peroxide of iron in its composition. It varies in colour from pale to dark reddish brown, or even nearly black.

The species has been recorded, with some reservation, by Dr. de Amicis from the Lower Pliocene of Sicily. (?) *Lower Pliocene. Recent.*

GENUS *Aschemonella*, BRADY.

Test very variable in form; usually consisting of irregular inflated sacs, either single and presenting several tubulated orifices or combined in branching series. *Recent.*

EXAMPLE.—*A. catenata*, Norman sp. (*Astrorhiza*), 'Proc. Roy. Soc.' vol. xxv. 1876, p. 213; Brady, 'Quart. Journ. Micr. Sci.' vol. xix. N.S. 1879, p. 42, pl. iv. figs. 12, 13.

This is an essentially deep-water type. The species above named is widely distributed. It has an irregularly branched test, with inflated chambers; and more than one orifice to each chamber is frequently seen. The shell wall is compact but thin, and the interior smooth, whilst the exterior is slightly rough in texture, and often coated with mud. *Recent.* (Plate 6, fig. 1.)

GENUS *Rhizammina*, BRADY.

Unattached masses of fine flexible, simple or branching, chitino-arenaceous tubes; more or less rough externally. *Gault. Recent.*

EXAMPLE.—*R. algæformis*, Brady, 'Quart. Journ. Micr. Sci.' vol. xix. N.S. 1879, p. 39, pl. iv. figs. 16, 17.

This form is seen under a variety of aspects, according to the nature of the sea bottom. Sometimes it is merely a branched flexible tube, roughened externally by adherent mud or fine sand, at others thickly encrusted with minute objects, as other Foraminifera, which the organism has selected from the surrounding ooze. It is a deep-water species. *Recent.* (Plate 6, figs. J, K.)

GENUS *Sagenina*, CHAPMAN.

Test a branching, reticulated, adherent, sandy tube, spread over the surface of shells or stones; apertures terminal.

The name *Sagenella*, given by H. B. Brady for this generic type, had been already used for a genus of the polyzoa by James Hall. The above definition of the genus naturally still holds good for these types. *Recent.*

EXAMPLE. — *Sagenina frondescens*, Brady sp., 'Quart. Journ. Micr. Sci.' vol. xix. N.S. 1879, p. 41, pl. v. fig. 1.

This peculiar branching form is especially restricted, in its distribution, to the shallow water of coral regions in the S. Pacific. Its ramifying test is found adherent to shells, *Halimeda* joints, and even Foraminifera, as *Cycloclypeus*. Since its occurrence in the 'Challenger' gatherings from the Admiralty and Friendly Islands *Sagenina* has been found in considerable abundance around the atoll of Funafuti, where it flourishes both inside the lagoon and on the outer reef. *Recent*. (Plate 6, fig. L.)

GENUS *Botellina*, CARPENTER.

Test subcylindrical, probably growing attached at one end; the other end rounded, and formed of loose sand-grains with interstitial openings. Interior filled with irregular septa, formed of coarse sand-grains slightly cemented together. *Recent*.

EXAMPLE.—*B. labyrinthica*, Brady, 'Quart. Journ. Micr. Sci.' vol. xxi N.S. 1881, p. 48; 'Rep. "Chall."' vol. ix. p. 279, pl. xxix. figs. 8–18.

This species is peculiar among the ASTRORHIZIDÆ in having a labyrinthic structure in the interior of the test. It is a singular fact that *B. labyrinthica*, the only representative of the genus by the way, has only occurred once, in dredgings made by the 'Porcupine' in the Faröe Channel, at 440 fathoms. *Recent*. (Plate 6, fig. M.)

GENUS *Haliphysema*, BOWERBANK.

Test columnar, growing attached by an expanded, convex, pseudo-polythalamous base; column straight or crooked, either simple and gradually increasing in size towards the apex or dividing into a number of branches. Test generally beset with sponge spicules ; aperture terminal. *Recent.*

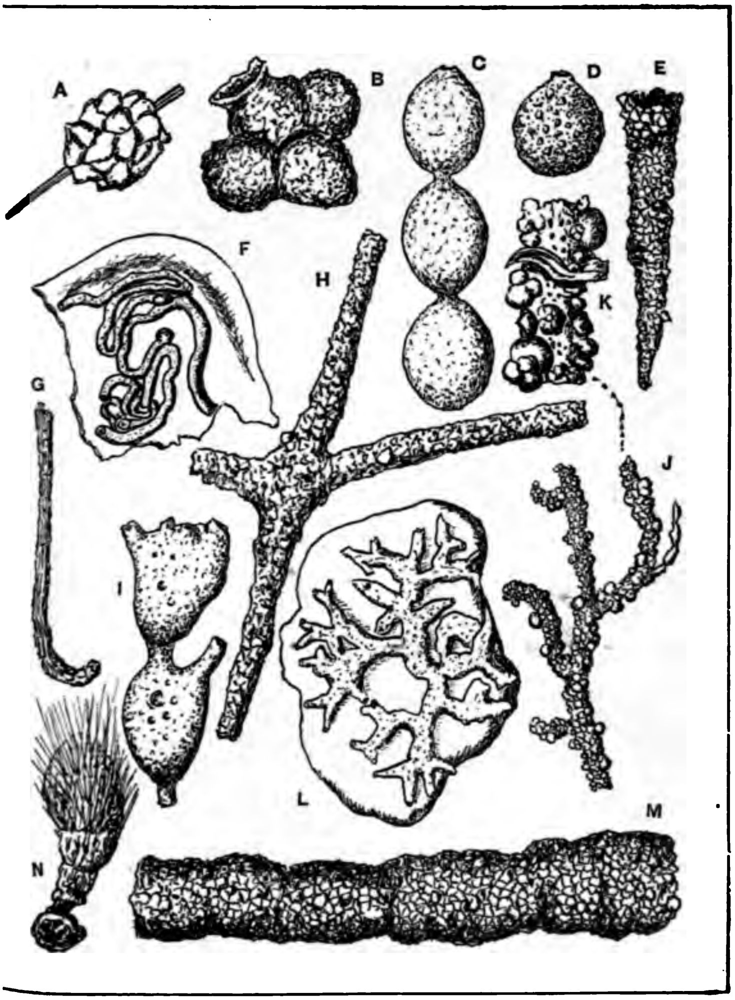
EXAMPLE.—*H. Tumanowiczii*, Bowerbank, 'Phil. Trans.' 1862, p. 1105, pl. lxxiii. fig. 3.

There are two species in the above genus, the example here selected being the better known. It grows adherent to various objects in low-tide pools or between tide-marks to a depth of 20 fathoms, and the tiny whitish tufty tests are often seen clustering on stems of sea-weed. Among other localities it has been found off Hastings, Torbay, Jersey, Colwyn Bay, and Dublin Bay. *Recent.* (Plate 6, fig. N.)

EXPLANATION OF PLATE 6.

Fig.
A. *Psammosphæra fusca*, Schulze (after Brady). × 20.
B. *Sorosphæra confusa*, Brady. × 8.
C. *Saccammina fusuliniformis*, M'Coy sp. × 4.
D. *Saccammina sphærica*, M. Sars (after Brady). × 4.
E. *Jaculella acuta*, Brady. × 4.
F. *Hyperammina vagans*, Brady. × 8.
G. *Marsipella cylindrica*, Brady. × 8.
H. *Rhabdammina abyssorum*, M. Sars. × 4.
I. *Aschemonella catenata*, Norman, sp. (after Brady). × 5.
J. *Rhizammina algæformis*, Brady. × 4.
K. *Rhizammina algæformis*, a more highly magnified fragment. × 20.
L. *Sagenina frondescens*, Brady sp. × 8.
M. *Botellina labyrinthica*, Brady. × 8.
N. *Haliphysema Tumanowiczii*, Bowerbank. × 17.

PLATE 6.



Family III. ASTRORHIZIDÆ (*concluded*).

CHAPTER X

THE FAMILY LITUOLIDÆ

THE LITUOLIDÆ are separated from the foregoing family of arenaceous rhizopods chiefly on account of their possessing truly septate tests, and their more regular form.

The septa are not always perfectly developed, and the interior of the test is frequently occupied by meandering or labyrinthic chambers.

In this family arenaceous isomorphs of nearly all the simpler porcellanous and hyaline types may be found: as, for example, in *Ammodiscus*, which resembles *Cornuspira* and *Spirillina*; the monothalamous form of *Reophax*, resembling *Lagena*; the uniserial *Reophax* and *Hormosina*, resembling *Nodosaria*; the complanate forms of *Haplophragmium*, resembling *Marginulina*, and *Cristellaria*; the *Haplophragmia* with inflated chambers, resembling *Globigerina*, *Rotalia*, and *Nonionina*; the attached form *Webbina*, resembling *Vitriwebbina*; and *Trochammina*, resembling *Anomalina* and *Rotalia*.

As in the ASTRORHIZIDÆ the tests of the Lituolids may be variously constructed of coarse or fine sand-grains held together with chitinous or ferruginous cement, as in *Reophax* and *Hormosina*; of calcareous sand with little or much calcareous and sarcodic cement, as in *Haddonia*; of the tests of smaller Foraminifera with or without an admixture of calcareous mud, as in certain species of *Haplophragmium* found in *Globigerina* Ooze; of sponge spicules and calcareous mud, as in *Reophax armatus*; or even consisting of tiny fusiform spicules of a calcareous nature formed by the rhizopod itself, as in *Carterina spiculotesta.*

The genera belonging to the sub-family LITUOLINÆ are associated together on account of the general structure of the test, which is coarsely arenaceous. The septation of the test is more often complete, as in *Reophax*, *Haplophragmium*, and *Placopsilina*; but in *Lituola*, *Haplostiche*, *Bdelloidina*, *Haddonia*, and *Polyphragma* the chambers are labyrinthic, and consequently the septation is interrupted or sinuous.

The genus *Polyphragma* is here placed with the typical lituolids instead of with the ENDOTHYRINÆ, since its chambers have this labyrinthic character well developed, and the test presents the ordinary coarse arenaceous appearance, without a preponderance of calcareous cement.

The labyrinthic genera in the LITUOLINÆ appear to be normally adherent to marine objects, as shells, stones, or algæ; and they are either attached to a partial extent by the proximal end of the test or are adherent along their whole length.

A thin arenaceous test is a feature of the next sub-family, the TROCHAMMININÆ. The external shell surface is more or less smooth, and the interior is glazed by a thin chitinous lining. Sometimes the arenaceous material composing the test is reduced to a minimum quantity under certain conditions, as in estuarine or brackish pools, the result being a thin membranous and flexible test, as, for example, in some species of the genus *Trochammina.*

The ENDOTHYRINÆ are not so well defined a group as the two previous; but they can be said to be generally characterised by an arenaceous test composed of calcareous particles, with a large proportion of calcareous cement; their shell-wall is often distinctly perforate. There is also a tendency for the internal shell structure to become cancellated, or broken up into a rudely cellular structure, but not to so great a degree as in the next sub-family of the LOFTUSIINÆ.

The ENDOTHYRINÆ is an entirely fossil group of organisms, and it is well represented in the Palæozoic rocks by *Nodosinella*, *Stacheia*, *Endothyra*, and *Bradyina*, whilst *Involutina* is restricted to the Jurassic series of the Mesozoic period. The genus *Stacheia* further extends its range from the Palæozoic into the Mesozoic rocks by its appearance, in some abundance, in certain marls of Rhætic and Liassic ages in England and France.

The types of subarenaceous *Patellinæ*, as *Orbitolina* and *Conulites*, are perhaps more conveniently separated from the first named genus; not on zoological grounds, however, for they represent the same morphological species of organism. For this latter reason Carpenter and Rupert Jones treated them as true *Patellinæ*, and the author has previously followed up their study on these lines (see 'Bibl. List,' No. 139). The subarenaceous group is nevertheless so important and distinct in the Cretaceous and Tertiary rocks that their separation seems to be necessary, especially as we follow the principle of classification by shell structure, which is the most convenient, as we have already seen, for a clear and systematic survey of the order.

The sub-family of the LOFTUSIINÆ comprises two genera only, in which the chambers are partially occupied with cancellated or labyrinthic developments of the shell-wall. The minute structure of the test in *Cyclammina* represents the same type of structure seen in the shell-wall of the other genus *Loftusia*. The latter form, however, attains a relatively gigantic size compared with the majority of Foraminifera; and although it has been regarded somewhat doubtfully as a rhizopod, chiefly on account of its size, it is now generally accepted as a true foraminifer. In both genera the interiors of the chambers are more or less filled up with the cancellated and labyrinthic shell-wall and septa. The microscopic appearance of the central part of *Cyclammina* and the first few whorls of *Loftusia* are strikingly similar. The contour of the test in *Loftusia* resembles *Alveolina*, and it may therefore be regarded as an isomorphous form of that genus.

A third genus was originally included in this sub-family—namely, *Parkeria*, from the Cambridge Greensand (Cenomanian)—but the structure of its test, although, like the porcellanous type *Keramosphæra*, or the hyaline *Gypsina globulus*, in general contour, in part resembles the hydroid *Hydractinia*, in its concentric manner of growth and the vertical pillars and septa, and in part shows affinities towards the Hydrocorallines in exhibiting in section what appear to be zooidal tubes disposed at intervals through the cœnenchyma, as in the allied genus *Stoliczaria* from the Trias of Cashmere.

Sub-family 1. LITUOLINÆ.

Test composed of coarse sand-grains, rough externally; often labyrinthic.

DIVISION A.—NON-LABYRINTHIC SERIES.

GENUS *Reophax*, MONTFORT.

Test free; composed either of a single flask-shaped chamber or of several, united in a straight, curved, or irregular line; never spiral. *Jurassic to Recent.*

EXAMPLES.—*R. difflugiformis*, Brady, 'Quart. Journ. Micr. Sci.' vol. xix. N.S. 1879, p. 51, pl. iv. figs. 3*a*, *b*.

This is a single-chambered form of *Reophax*, which has a wide range in modern deposits both as to depth and locality. In fossil deposits its occurrence commences with the Rhætic series in Somersetshire, described by the author; and in the Jurassic rocks of Switzerland, recorded by Haeusler. It also appears to occur in the Gault of France, and is known from Pleistocene deposits at Cumbrae. *Jurassic to Recent.* (Plate 7, fig. A.)

R. scorpiurus, Montfort, 'Conchyl. Systém.' vol. i. 1808, p. 330, 83^{e} 'genre.'

Of the many species of Foraminifera which are widely distributed over the oceanic areas of the globe this is one of the better known. It constructs its test typically of coarse sand-grains, but where restricted to an oozy or spicular deposit it selects small shells or spicules, as the case may be, to form its test.

The geological range of this form commences in the Jurassic strata and continues to the present time. (Plate 7, fig. B.)

GENUS *Haplophragmium*, REUSS.

Test free; partially or entirely spiral; nautiloid or crozier-shaped; chambers numerous. *Carboniferous to Recent.*

The sub-genus *Coskinolina*, Stache, is distinguished by the form of its later chambers, which widen rapidly.

EXAMPLE.—*H. Humboldti*, Reuss (*Spirolina*), 'Zeitschr. Deutsch. Geol. Gesellsch.' vol. iii. 1851, p. 65, pl. iii. figs. 17, 18.

This neat and typical crozier-shaped *Haplophragmium* makes its first appearance as a fossil in the Aptian beds of Surrey, and it was also described from various deposits of Lower Tertiary age in Germany and Hungary. It does not exactly agree in specific characters with any form of the same genus now found living. (Plate 7, fig. C.)

H. nonioninoides, Reuss, ' Sitzungsb. k. Ak. Wiss. Wien,' vol. xlvi. 1862, p. 30, pl. i. fig. 8.

The test of this fossil form is composed of sand-particles of medium coarseness, of a pale grey to a ruddy brown colour, with occasional chips of green glauconite interspersed. The contour of the shell is well rounded and fairly subglobular in form, but flattened at the umbilici. The arched slitlike aperture is very nearly central on the septal face of the shell. As to distribution in geological time, it is quite a restricted form; for it first appears in the Aptian formation of England and afterwards in the Gault both of England and Germany. (Plate 7, fig. D.)

GENUS *Placopsilina*, D'ORBIGNY.

Chambers plano-convex, adherent. *Jurassic to Recent.*

EXAMPLE.—*P. cenomana*, D'Orbigny, ' Prodrome Paléont.' vol. ii. 1850, p. 185, No. 758; Reuss, ' Denkschr. k. Akad. Wiss. Wien,' vol. vii. 1854, p. 71, pl. xxviii. figs. 4, 5.

Some of the modifications of this species consist of a long sinuous series of adherent segments, whilst some allied forms are monothalamous. The figure given here is from an intermediate type of shell, and appears to be constructed chiefly of coral sand. The test is usually seen with a spiral commencement, afterwards running off into a linear series. Some of the published figures of this species undoubtedly represent other types of shell structure, as *Nubecularia*, for certain authors have not recognised these differential characters of the foraminiferal test.

P. cenomana is said to have occurred in the Lower Lias marls of the West of France. It occurs with some frequency in the Upper Jurassic strata; again in the Gault and Upper Greensand, and later in certain Tertiary deposits, though rarely. It is, at the present day, most usual in shallow water. (Plate 7, fig. E.)

GENUS *Crithionina*, GOËS.

Walls of test generally thick, composed of fine arenaceous mud. Normally attached. The interior a simple cavity, or divided by irregular, sometimes by radial, septa. Contour hemispherical, sublenticular, or depressed. Apertures few and indistinct.

On account of the septate interior of several species of this genus it is here regarded as one of the non-labyrinthic LITUOLIDÆ. *Recent.*

EXAMPLE.—*Crithionina mammilla*, Goës, 'Kongl. Svenska Vetenskaps-Akad. Handlingar,' vol. xxv. No. 9, 1894, p. 15, pl. iii. figs. 34–36.

Usually adherent, subglobose, somewhat smooth. Walls thick and spongy. Central chamber subspherical, having a diameter equal to the thickness of the walls; undivided. Apertures few and small. Constructed of fine detrital and argillaceous material. Dr. Goës found his specimens in the Skagerack at a depth of 57 fathoms. It has since been recorded by

Millet from the Malay Archipelago. (Plate 7, figs. F, *f*.)

GENUS *Verrucina*, GOËS.

Test adherent, constructed of agglutinated sand, divided in the interior into a few more or less regular chambers, having an outlet in the sunken apex of the test. *Recent.*

EXAMPLE.—*V. rudis*, GOËS, 'Bull. Mus. Comp. Zool. Harvard,' vol. xxix. No. 1, part xx. 1896, p. 25, pl. i. figs. 15, 16.

The shape of the test is irregularly ovoid, adherent, with a rough surface. The sunken top carries the irregular apertures, communicating with the septate interior. Found by Goës in the Pacific, at a depth of 772 fathoms. *Recent.* (Plate 7, fig. G.)

DIVISION B.—SERIES WITH LABYRINTHIC CHAMBERS.

GENUS *Haplostiche*, REUSS.

Test free, uniserial, straight, or arcuate; never spiral. Chambers labyrinthic. Aperture terminal; porous or dendritic, rarely simple.

EXAMPLE.—*H. Soldanii*, Jones and Parker sp. (*Lituola*), 'Quart. Journ. Geol. Soc.' vol. xvi. 1860, p. 307, No. 184; Brady, 'Rep. "Chall."' vol. ix. 1884, p. 318, pl. xxxii. figs. 12–18.

This series has an elongate, subcylindrical, or ovate test, with tapering or rounded ends. Segments convex, slightly embracing, subdivided by irregular secondary septa. Sometimes measures as much as $\frac{3}{10}$ inch (7·5 mm.)

This striking form is frequently found in dredgings from the West Indies and the Pacific, among other localities. It ranges in depth from about 40 to 435 fathoms. As a fossil it first occurs in the Miocene. *Miocene to Recent.* (Plate 7, figs. H, *h*.)

GENUS *Lituola*, LAMARCK.

Test free, partially or entirely spiral; nautiloid or crozier-shaped. *Carboniferous to Recent.*

EXAMPLE.—*L. placentula*, Chapman, 'Ann. Mag. Nat. Hist.' ser. 7, vol. iii. 1899, p. 54, figs. 2*a*, *b*.

Test complanate, irregularly suboval; composed of coarse arenaceous particles with much cement of a finer sandy nature. Interior labyrinthic. The general aspect of the test shows this form to have had a spiral, but the separate segments are obscure. *Cretaceous* (*Cambridge Greensand*). (Plate 7, fig. I.)

GENUS *Bdelloidina*, CARTER.

Test adherent; chambers linear, vermiform, approximated, intercommunicating by a row of pores seen on each septal face. *Cretaceous*, *Recent.*

EXAMPLE.—*B. aggregata*, Carter, 'Ann. Mag. Nat. Hist.' ser. 4, vol. xix. 1877, p. 201, pl. xiii. figs. 1–8.

This is apparently the only species of the above genus. The test is generally constructed of coarse calcareous sand, the exterior of the shell being rough, the internal surface smooth. With the exception of one fine example met with in the Chalk this form is almost confined to recent deposits, usually in the neighbourhood of coral reefs. Its range in depth is from 25 to 63 fathoms. (Plate 7, fig. I.)

GENUS *Haddonia*, CHAPMAN.

Test calcareo-arenaceous; adherent and sinuous; the commencement sometimes straight, sometimes spiral. Chambers linear and narrower in the line of growth than laterally. Sutures roughly parallel, but sometimes quite irregular. Chambers imperfectly septate or coarsely labyrinthic. Shell-wall perforated by a series of coarse pores. Aperture a crescentic or horseshoe-shaped slit.

EXAMPLE.—*H. torresiensis*, Chapman, 'Journ. Linn. Soc. Lond., Zoology,' vol. xxvi. 1898, p. 454, pl. xxviii.

This species was originally found in abundance affixed to a mass of rough coral rock from Torres Strait. It has since occurred in considerable numbers from the reef of the Funafuti atoll. The colour of the shell-wall is from whitish to cream colour or pale brown; the breadth of the chambers about twice their height, here and there subdivided obliquely, somewhat in the manner of *Textularia*, but very irregularly, the general plan being a moniliform series of segments. Aperture usually crescent-shaped, sometimes gaping, but more often having a valvular flap, formed by a prolongation of the superior surface of the test, which nearly closes up the orifice, as in *Valvulina* and certain of the *Miliolinæ*. *Recent.* (Plate 7, fig. K.)

EXPLANATION OF PLATE 7.

FIG.

A. *Reophax difflugiformis*, Brady. × 50.

B. *R. scorpiurus*, Montfort (after Brady). × 15.

C. *Haplophragmium Humboldti*, Reuss (after Hantken). × 18.

D. *H. nonioninoides*, Reuss (after Chapman). × 30.

E. *Placopsilina cenomana*, D'Orbigny (after Brady). × 30.

F, *f*. *Crithionina mammilla*, Goës. × 11.

G. *Verrucina rudis*, Goës. × 7.

H, *h*. *Haplostiche Soldanii*, Jones and Parker (after Brady). × 10.

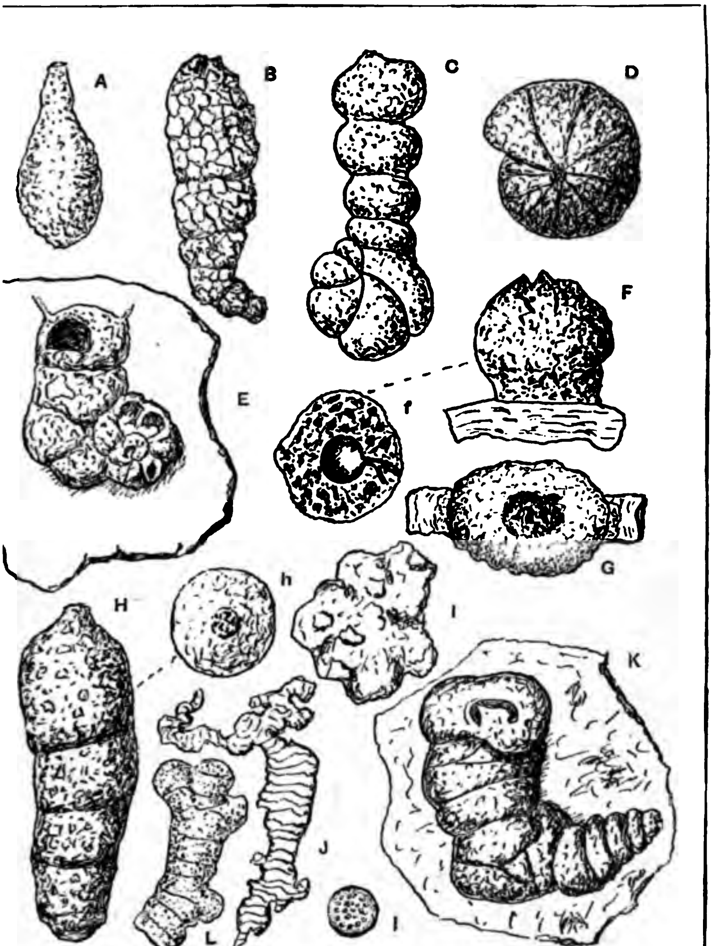
I. *Lituola placentula*, Chapman. × 14.

J. *Bdelloidina aggregata*, Carter (after M. Wright's drawing). × 5.

K. *Haddonia torresiensis*, Chapman. × 5.

L, *l*. *Polyphragma cribrosum*, Reuss (after Perner). × 8.

PLATE 7.



FAMILY IV. LITUOLIDÆ.

L

GENUS *Polyphragma*, REUSS.

Test cylindrical, growing attached by the basal extremity; consisting of a line of very short cylindrical segments placed one above the other. Interior of the chambers labyrinthic; aperture terminal, cribrate (sieve-like). *Cretaceous.*

EXAMPLE. — *P. cribrosum*, Reuss (*Lichenopora*), 'Versteinerungen der böhm. Kreideformation,' pt. ii. 1846, pp. 60, 123, pl. xiv. fig. 10, pl. xxiv. figs. 3–5.

The above species was found in the chalk formation of Bohemia by Reuss, and later by Perner in the Cenomanian of that country. The affinities of the genus towards the semi-labyrinthic forms of *Haplophragmium* are seen in the internal structure of the segments as revealed by thin sections of the test, as well as by the nature of the septal face, which is cribrate, as in *Haplophragmium irregulare.* The species is found adherent to shells and *Cidaris* spines. Steinmann has referred this genus to the group of the pharetrone sponges, but the minute structure of the walls of the organism does not support this view. *Cretaceous.* (Plate 7, figs. L, *l.*)

Sub-family 2. TROCHAMMININÆ.

Test thin; composed of minute sand-grains incorporated with calcareous or other inorganic cement, or embedded in a chitinous membrane; exterior smooth, often polished; interior smooth or (rarely) reticulated; chambers never labyrinthic.

GENUS *Thurammina*, BRADY.

Test usually monothalamous, inflated or compressed, with apertures situated at the summits of surface mammillæ. *Jurassic to Recent.*

EXAMPLE.—*T. papillata*, Brady, 'Quart. Journ. Micr. Sci.' vol. xix. N.S. 1879, p. 45, pl. v. figs. 4–8.

The variability shown in this species is very great, the characteristic papillæ being in some specimens few, in others very numerous, and imparting quite a rugose appearance to the test. The interior is sometimes occupied by another globular chamber, after the manner of *Orbulina*, with which form it presents some points of isomorphism. It is a deep or moderately deep water species. The geological range of *T. papillata* commences with the Jurassic beds of Switzerland, in which they were discovered by Haeusler. *Jurassic to Recent.* (Plate 8, fig. A.)

The sub-genus *Thuramminopsis* was established by Haeusler for certain types of Jurassic Foraminifera allied to the above genus, but which are much more irregular in growth and consist of a multiple series of chambers, on the internal walls of which a system of tube-like ridges are apparent. The external surfaces of the test are papillate, especially at the irregular outgrowths, after the manner of the typical *Thurammina*. *Thuramminopsis canaliculata* was described by Haeusler from the sponge beds of the Jurassic 'Transversarius' zone of Aargau, Switzerland ('Neues Jahrbuch,' 1883, vol. ii. p. 69, pl. iv.)

Genus *Hippocrepina*, Parker.

Test monothalamous, elongate; broad and rounded at one end, tapering to a point at the other; aperture large, curved or irregular. *Recent.*

Example. — *H. indivisa*, Parker (in Dawson's paper), 'Canad. Nat.' N.S. vol. v. 1870, pp. 176, 180, fig. 2.

This interesting little species is the only form in the genus. It is recognised by its finely sandy texture, the thin test, and undivided interior. The root-like test bears a somewhat crescentic or horseshoe-shaped opening at the broad end, and surrounded by a thickened rim. The species is entirely confined to northern seas of high latitudes. It has been found at the mouth of the River St. Lawrence, 16–20 fathoms, by Dr. G. M. Dawson; off Greenland in 10 and 13 fathoms by Norman and Goës; and at Novaya Zemlaia, 10–15 fathoms, by Brady. *Recent.* (Plate 8, figs. B, *b*.)

Genus *Hormosina*, Brady.

Test free, consisting sometimes of one chamber, but more often of a series of chambers, which are subglobular, fusiform, or pyriform, joined in a single straight or arcuate series. Walls thin, smooth externally; texture finely arenaceous; coloured variously yellow or brown. *Recent.*

Example.—*H. ovicula*, Brady, 'Quart. Journ. Micr. Sci.' vol. xix. N.S. 1879, p. 61, pl. iv. fig. 6.

The test of this species consists of several fusiform segments forming a slender moniliform series. The junction of one segment with the other is usually marked on the stolon tube by a darker brown circlet around the shell. This species is solely a recent form and affects deep water. The 'Challenger' dredging yields this species from samples of over 1,000 fathoms in every case. Goës records it from the Pacific in shallower water, ranging to 300 fathoms. *Recent.* (Plate 8, fig. C.)

GENUS *Ammodiscus*, REUSS.

Test free, formed of a tube coiled upon itself in various ways; sometimes constricted at intervals, but never septate. *Carboniferous to Recent.*

EXAMPLE.—*A. incertus*, D'Orbigny sp. (*Operculina*), 'Foram. Cuba,' 1839, p. 71, pl. vi. figs. 16, 17.

This, the simplest form of the genus, consists of a circular tube coiled in plano-spiral fashion. It made its first appearance, so far as our knowledge goes, in the Carboniferous limestone series, where it is sometimes found in great abundance; and it is found with some frequency in nearly all later formations. The species is liable to great variation, the tube showing various degrees of flattening; and it often tends to depart from the plan of a flat coiled shell, and even to bend and twist on itself. The structure of the test is always more or less finely arenaceous.

The specimens dredged up from existing sea bottoms are often as large as 3 mm. across. *A. incertus* has an extensive range in depth; Goës found it in the Pacific Ocean from 600 to 1,200 fathoms, and in the Caribbean Sea and the Gulf of Mexico from 200 to 1,800 fathoms. The 'Challenger' obtained it from the N. Atlantic from 450 fathoms and deeper, and from the N. Pacific in the very deep area at 3,125 fathoms. It has been found as far north as the southern coast of Norway and the Faröe Channel. *Carboniferous to Recent.* (Plate 8, fig. D.)

GENUS *Trochammina*, PARKER and JONES.

Test free, or rarely adherent; rotaliform, nautiloid, or trochoid; more or less distinctly septate. *Lower Lias to Recent.*

This genus was subsequently restricted in its meaning from the original sense intended by Parker and Jones by H. B. Brady, who found it necessary to distinguish between the non-septate and the septate forms of finely arenaceous Foraminifera.

EXAMPLE.—*T. lituiformis*, Brady, 'Quart. Journ. Micr. Sci.' vol. xix. N.S. 1879, p. 59, pl. v. fig. 16.

Test free, crozier-shaped; consisting of an irregularly septate or pseudo-septate tube, spiral at its commencement, subsequently linear.

Other well-known modifications of *Trochammina* are *T. squamata*, Jones and Parker, isomorphous with the thin trochoid *Discorbinæ* and *T. inflata* (Montagu), isomorphous with *Discorbina rugosa*.

T. lituiformis is a recent species only, and was found in depths varying from 390 to 900 fathoms. (Plate 8, fig. E.)

GENUS *Carterina*, BRADY.

Test rotaliform, convex; normally adherent; with pointed oval calcareous spicules formed by the organism itself. *Recent.*

EXAMPLE.—*C. spiculotesta*, Carter sp. (Rotalia), 'Ann. and Mag. Nat. Hist.' ser. 4, vol. xx. 1877, p. 470, pl. xvi. .

This singular little organism is peculiar in being constructed of little spicular bodies secreted by the sarcode; they are arranged somewhat regularly, with their long axes in the direction of the peripherical margin of the test. The central portion of the test is usually a dark purplish brown, the outer chambers gradually fading off to white.

Carter's specimens came from the South Pacific and the Gulf of Manaar; Brady records it from the Gulf of Suez at 40 fathoms, and Millett from the Malay Archipelago.

Recently the writer has obtained the same species from the dredgings at Funafuti, where it occurs outside the reef at 36, 50, and 60 fathoms, and in the lagoon at 19, 20, 25, and 26 fathoms, usually attached to *Halimeda* fronds. *Recent.* (Plate 8, figs. F, *f*.)

GENUS *Webbina*, D'ORBIGNY.

Test adherent; consisting either of a single tent-like chamber or of a number of such chambers connected by adherent stoloniferous tubes. It is isomorphous with the hyaline form *Vitriwebbina.*

Example.—*W. clavata*, Jones and Parker sp. (*Trochammina*), 'Quart. Journ. Geol. Soc.' vol. xvi. 1860, p. 304; Brady, 'Rep. "Chall."' vol. ix. 1884, p. 349, pl. xli. figs. 12–16.

This simply constructed organism is found attached to shells or stones, sometimes at great depths. Parker and Jones record its occurrence in the Mediterranean at depths from 90 to 1,700 fathoms. It is also fairly well distributed in the various oceanic deposits. *Recent.* (Plate 8, fig. G.)

Sub-family 3. ENDOTHYRINÆ.

Test more calcareous and less sandy than in the other groups of the Lituolidæ; sometimes perforate; septation usually distinct.

Genus *Nodosinella*, Brady.

Test free, straight, arcuate, or crooked, never spiral; formed either of a tube constricted at intervals or of a single series of segments variously combined. Test arenaceous, often smooth externally, imperforate, but sometimes having pustulate orifices at various points on the surface. Wall of test thick, with a labyrinthic structure. Aperture variable, simple or compound. *Carboniferous to Rhætic.*

Example. — *N. cylindrica*, Brady, 'Monograph Carb. and Perm. Foram.' (Pal. Soc.), 1876, p. 104, pl. vii. figs. 4-7.

These curious little fossils are mostly found in washings from the rotten Carboniferous limestone. Brady compares them with *Botellina*, from which, however, they differ in the finer arenaceous structure of the test. *Carboniferous.* (Plate 8, fig. H.)

GENUS *Stacheia*, BRADY.

Test adherent or free; composed of numerous segments subdivided in their interior, or of an acervuline mass of chamberlets, sometimes arranged in layers, sometimes confused, or of a thick-walled test with acervuline or labyrinthic structure, and with the interior subdivided into numerous elongate sinuous cavities (the latter characters especially applying to fossils of the genus from the Rhætic). Apertures simple but irregular, terminal, or scattered over the surface of the test. Texture subarenaceous, composed of fine sand, sometimes admixed with coarser material, and with a calcareous or chitinous cement; imperforate. *Silurian to Lias.*

EXAMPLE.—*S. congesta*, Brady, 'Monogr. Carb. and Perm. Foram.' (Pol. Soc.), 1876, p. 117, pl. ix. figs. 1–5.

Of the many different modifications of this genus the above species is taken as a simple example. It is typically adherent, and usually grows round certain objects of attachment. The areolation of the shell structure and its method of growth caused Dr. Brady to compare this species with the isomorphous hyaline form *Gypsina inhærens.* Brady's examples came from the Carboniferous limestone of England and Scotland. The author has described the same form from the Rhætic of Somerset. *Carboniferous. Rhætic.* (Plate 8, fig. M.)

GENUS *Involutina*, TERQUEM.

Test discoidal to conical; consisting of a coiled tube wound spirally either in a plane or to form a hollow cone. When conical the hollow inferior surface is filled in with exogenous shell-growth; when discoidal both surfaces are thickened with exogenous tubercles. The tube is sometimes partitioned at intervals by incomplete septa. Aperture circular or slit-like. Shell-wall more or less perforate. *Jurassic.*

EXAMPLE.—*I. Remesiana*, Chapman, 'Journ. Linn. Soc. Lond., Zool.' vol. xxviii. 1900, p. 29, pl. 5, figs. 5, *a–c*.

This form has a conical test, depressed, and consisting of a simple coiled tube of about five whorls; the sutures distinct. The inferior surface is slightly convex, and covered with papillæ of exogenous shell growth, excepting the last whorl, which is marked on the periphery with distinct furrows at right angles to the edge. The test is finely perforate on the inner parts of the tubes, and calcareo-arenaceous on the outer. The aperture opens on the inferior side of the test. *Upper Jurassic (Tithonian)*, of Nesselsdorf, Austria. (Plate 8, figs. 1, *i*, *i′*.)

GENUS *Orbitolina*, D'ORBIGNY.

Test conical, more or less depressed, consisting of an external series of annular or more rarely spiral chambers, divided into chamberlets; also a central aggregation of compressed chamberlets, in which the partitions are either labyrinthic or arranged in tiers. Base of cone usually excavate. Shell-wall fairly stout, and subarenaceous in texture. Lower and Upper Cretaceous.

A very flat and explanate type of this genus is the *Cyclolina cretacea* of D'Orbigny.

EXAMPLE.—*O. concava*, Lamarck sp.

This is one of the largest species of the genus, often reaching a diameter of 2 centimetres. The external layer of chambers are in this form arranged in an annular series, and the central group of chamberlets are more or less acervuline. Cenomanian. (Plate 8, figs. J, *j*.)

GENUS *Conulites*, CARTER.

Test conical, usually steep, the height being greater than the width at the base. The external series commences with a distinct spiral, which either continues to the last coil or subsequently gives place to an annular arrangement. The external chamberlets, into which the chambers are divided, are separated by straight partitions forming rectangular cells, and the chamberlets themselves are partially divided by one to three short dissepiments. The internal portion of the test is divided into curved floors, and subdivided by secondary labyrinthic partitions. *Eocene.* (?) *Lower Miocene.*

Example.—*C. ægyptiensis*, Chapman, 'Geol. Mag.,' N.S., Decade 4, vol. vii. 1900, p. 11, pl. ii. figs. 1–3.

Test conoidal, in vertical section nearly equilateral, the two sides slightly convex, straight, or incurved in the middle of the test; base circular in outline, and with a slightly convex surface; peripheral edge rounded. The base of the test, the homologue of the septal face, is finely porous, or perforate. (?) *Lower Miocene* of Egypt; constituting a large proportion of a limestone. (Plate 8, figs. K, *k*.)

Genus *Endothyra*, Phillips.

Test polythalamous; nautiloid or rotaliform; aperture simple, situated at the inner margin of the final chamber. *Carboniferous to Trias.*

Example.—*E. Bowmani*, Phillips, 'Proc. Geol. Tech. Soc.,' West Riding, Yorks, vol. ii. 1845, p. 279, pl. vii. fig. 1.

Test depressed, usually consisting of two or three oblique convolutions, of which but little more than the last is visible on the exterior. Margin thick, rounded, lobulate; septal lines depressed. Segments inflated; variable in number, usually from seven to ten in each whorl. Aperture single, simple.

This species is usually the chief foraminiferal constituent of the *Endothyra* limestones often met with in England, Wales, Scotland, Ireland, the

Caucasus, and Indiana. *Carboniferous.* (Plate 8, figs. L, *l*.)

The sub-genus *Bradyina*, Möller, is distinguished from *Endothyra* (*typica*) in having a crescentic series of pores on the septal face of the last chamber, as well as a series of pores in the septal depressions of the shell.

EXAMPLE.—*Bradyina nautiliformis*, Möller, 'Mém. Ac. Imp. Sci. St.-Pétersbourg,' ser. 7, vol. xxv. No. 9, 1878, p. 83, pl. iii. figs. 4*a–d*; pl. x. fig. 3*a*, *b*. *Carboniferous.*

The sub-genus *Cribrospira*, Möller, is distinguished by the cribrate orifices on the septal face of the shell.

EXAMPLE. — *Cribrospira Panderi*, Möller, *ibid.* 1878, p. 87, pl. iv. figs. 1*a–c*; pl. x. figs. 1*a*, *b*. *Carboniferous.*

Sub-family 4. LOFTUSIINÆ.

Test of relatively large size; lenticular, spherical or fusiform; constructed either on a spiral plan or in concentric layers, the chamber cavities occupied to a large extent by the excessive development of the finely arenaceous cancellated walls.

GENUS *Cyclammina*, BRADY.

Test spiral, nautiloid; lenticular or subglobular; smooth externally; chambers numerous, involute. *Pliocene and Recent.*

EXAMPLE.—*C. cancellata*, Brady, 'Quart. Journ.

Micr. Sci.' vol. xix. N.S. 1879, p. 62 ; 'Rep. "Chall."' vol. ix. 1884, p. 351, pl. xxxvii. figs. 8–16.

This is a large compressed form, with slightly sinuous suture lines and rounded peripheral edge. The internal structure of the first chambers is entirely cancellated. The apertures on the septal face consist of a number of pores communicating with the labyrinthic interior. In recent gatherings this species extends from 75 to 2,900 fathoms. Goës found it in the Pacific at depths from 660 to 995 fathoms ; and in the Caribbean Sea from 196 to 1,830 fathoms. *Pliocene and Recent.* (Plate 8, figs. N, *n.*)

GENUS *Loftusia*, BRADY.

Test of large size, spiral; elongated in the direction of the axis of convolution; fusiform or elliptical; resembling *Alveolina* in contour.

EXAMPLE.—*L. persica*, Carpenter and Brady, 'Phil. Trans.' 1869, p. 739, pls. lxvii.–lxxx.

There can be little doubt, after a careful examination of the minute structure of this fossil, that we are dealing with a Foraminiferon rather than a Hydrozoön. The construction of the test agrees in every way with *Alveolina* and *Fusulina*, and the labyrinthic character of its walls proclaims its affinities with *Cyclammina*. *Tertiary*, Persia. (Plate 8, figs. O, *o.*)

EXPLANATION OF PLATE 8.

FIG.

A. *Thurammina papillata*, Brady. × 15.

B, *b*. *Hippocrepina indivisa*, Parker (after Brady): *b*, = oral aspect. × 20.

C. *Hormosina ovicula*, Brady. × 8.

D. *Ammodiscus incertus*, D'Orbigny sp. × 25.

E. *Trochammina lituiformis*, Brady. × 14.

F, *f*. *Carterina spiculotesta*, Carter (after Brady): F = superior aspect × 50; *f* = a fragment of test × 100.

G. *Webbina clavata*, Parker and Jones sp. (after Goës). × 20.

H. *Nodosinella cylindrica*, Brady. × 15.

I, *i*, *i'*. *Involutina Remesiana*, Chapman; I = superior surface; *i* = inferior, granulate, surface; *i'* = median, vertical section of test. × 15.

J, *j*. *Orbitolina concava*, Lamarck sp.: J = superior aspect; *j* = vertical section through the test. Natural size.

K, *k*. *Conulites ægyptiensis*, Chapman sp.: K = superior aspect; *k* = vertical section through the test. × 2½.

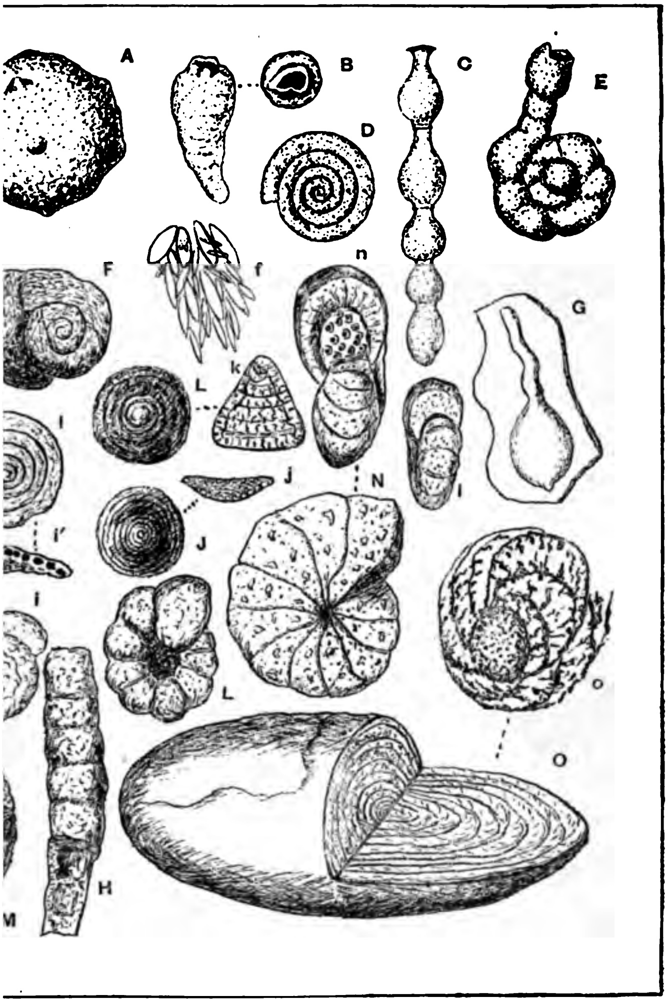
L, *l*. *Endothyra Bowmani*, Phillips (after Brady): *l* = peripheral aspect. × 25.

M. *Stacheia congesta*, Brady. × 25.

N, *n*. *Cyclammina cancellata*, Brady: N = lateral aspect; *n* = peripheral aspect. × 9.

O, *o*. *Loftusia persica*, Brady and Carpenter: O = natural appearance, cut to show internal structure; *o* = central portion in transverse section, showing the labyrinthic shell-wall and arrangement of the primary chambers. × 4.

PLATE 8.



FAMILY IV. LITUOLIDÆ (*concluded*).

CHAPTER XI

THE FAMILY TEXTULARIIDÆ

this family the usual texture of the test is naceous; but this is by no means a rule, for nearly the smaller species are hyaline, and in some cases type of shell-structure is typical of an entire us.

The relationships of the various types constituting family are very apparent from the fact that the necting links are numerous, and the plans of wth, though diverse, are of definite conformation. general plans on which the shells are constructed either as a double series of segments placed rnately in relation to each other, and in the same ne of growth, or as a triserial group of segments; certain genera the double or triple series is spi- y twisted; in others the arrangement is confused. ere is also a tendency for certain forms to take at different stages, diverse lines of growth, ally from the more complex to the simpler; as, example, *Bigenerina*, which begins with a biserial angement followed by a uniserial set of segments; *lavulina*, which is at first triserial and afterwards serial.

The sub-family of the TEXTULARIINÆ consists of se forms which are either biserial or triserial, and which exhibit a succession of segments joined together in a regular manner. There are modifications of these fundamental types in which two or even three plans of growth are seen (bimorphous and trimorphous forms).

The larger species are arenaceous, the smaller ones usually hyaline, and conspicuously perforate.

The sub-family BULIMININÆ includes types of shell-structure which may be either triserial or biserial, but spirally wound round the axis of growth. The attenuated and feebly developed species are usually biserial in arrangement, sometimes twisted, sometimes not, but differing in other points when compared with the typical textularid shell, as, for example, in the position and shape of the aperture.

The most complex of the textularid forms are grouped together in the next sub-family, the CASSIDULININÆ. Here the plan of growth may be explained by imagining a *Textularia* coiled upon itself, as in *Cassidulina*. A modification of this plan is seen in *Ehrenbergina*, in which the shell is partly unrolled, as it were; and consequently shows a convex dorsal surface and a concave side containing the early spiral portion. The test in this group in all cases is hyaline, and usually surface-polished.

Sub-family 1. TEXTULARIINÆ.

Test having a biserial or triserial arrangement of chambers. Sometimes bimorphous or even trimorphous.

GENUS *Textularia*, DEFRANCE.

Segments in two rows alternating with each other; normal aperture an arched slit at the base of the inner wall of the last segment. *Cambrian to Recent.*

This genus is very important as a foraminiferal type. Its distribution through almost all the principal fossiliferous rocks is very striking, there being hardly an instance of a foraminiferal fauna without some representatives of the genus.

EXAMPLES.—*T. rugosa*, Reuss sp. (*Plecanium*), 'Sitzungsberichte d. k. Ak. Wiss. Wien,' vol. lix. 1869, p. 453, pl. i. fig. 3 *a*, *b*.

This species is easily recognised by the imbricated appearance of the suture lines. It is at the present day a familiar coral-reef species, and attains to quite a large size. The writer has recently found specimens dredged at Funafuti, in the Pacific, measuring as much as 5 mm. in length. It is very rarely found in deeper water than 30 fathoms. *Oligocene to Recent.* (Plate 9, fig. A.)

T. complanata, Reuss sp. (*Proroporus*), 'Sitzungsb. d. k. Ak. Wiss. Wien,' vol. xl. 1860, pl. 231, pl. xii. figs. 5 *a*, *b*.

The flattened, complanate textularians have a somewhat modified aperture, which in this particular form appears as a circular aperture placed on a slight prolongation of the upper margin of the last chamber. *T. complanata* is a very restricted species as to age, for it has only been recorded from Cretaceous beds, in Germany and England, of about the period of the Gault. (Plate 9, fig. B.)

GENUS *Cuneolina*, D'ORBIGNY.

Test textularian, complanate; compressed in a direction at right angles to the normal plane, so that the two alternating series of segments appear on the narrow lateral edges. *Cretaceous.*

EXAMPLE.—*C. pavonia*, D'Orbigny, 'Foram. Foss. Vienne,' 1846, p. 253, pl. xxi. figs. 50-52.

This interesting species is the sole representative of the genus, and was described by D'Orbigny from the Lower Chalk, near the mouth of the Charente. Although the arrangement of the segments is distinctly textularian, the aperture, instead of being slitlike, as we might expect, is represented by a row of pores at the junction of the penultimate and last segments. It is not unusual, however, in other genera to find the same type exhibiting a diversity of character in this respect. For example, in the genus *Peneroplis* some of the forms which are complanate have a similar row of pores on the apertural plane, whilst the stouter kinds have a slitlike or branching orifice.

GENUS *Verneuilina*, D'ORBIGNY.

Test triserial, with a textularian aperture. *Lower Cretaceous to Recent.*

EXAMPLE.—*V. spinulosa*, Reuss, 'Denkschrift d. k. Ak. Wiss. Wien,' vol. i. 1849, p. 347, pl. xlvii. figs. 12 *a–c*.

The triserial arrangement of the segments is very clearly seen in this species. The angles of the segments forming the salient edges of the test are prolonged by exogenous shell growth into spines, which in specimens from clean and well-preserved dredgings are sometimes of considerable length and delicacy. Besides being found in the *Chalk* this species is frequent in many succeeding formations, as, for instance, the *Miocene* of Austria, Bavaria, and Malta, the *Pliocene* of Italy, and others of still later age. By its occurrence in recent dredgings we find it is most at home in depths of less than 100 fathoms. (Plate 9, fig. D.)

GENUS *Tritaxia*, REUSS.

Test triserial, sometimes dimorphous, with a simple produced central aperture. *Lower Cretaceous to Recent.*

EXAMPLE.—*T. tricarinata*, Reuss, 'Verstein. böhm. Kreideform.' pt. i. 1845, p. 39, pl. viii. fig. 60.

This typically Cretaceous form is still represented very sparingly in our present seas. It was an abundant form in Upper Cretaceous times, and is most characteristic of the Lower Greensand, the Upper Gault, and the Chalk-Marl in England. *Lower Cretaceous to Recent.* (Plate 9, fig. E.)

GENUS *Chrysalidina*, D'ORBIGNY.

Test triserial (sometimes dimorphous—that is to say, triserial at commencement and afterwards uniserial), with a porous septal face. *Cretaceous. Recent.*

Example.—*C. dimorpha*, Brady, 'Rep. "Chall."' vol. iv. 1884, p. 388, pl. xlvi. figs. 20, 21.

This is a particularly interesting species, on account of the dimorphous arrangement of its segments, which at first are triserial, as in *Verneuilina*, and afterwards uniserial, as in the later segments of *Clavulina*. It is confined to fairly shallow water in tropical areas. *Recent.* (Plate 9, fig. F.)

Dimorphous (*Textularian*) Forms.

Genus *Bigenerina*, D'Orbigny.

Early chambers textularian; later chambers uniserial and rectilinear. *Carboniferous to Recent.*

Example.—*B. capreolus*, D'Orbigny sp. (*Vulvulina*), 'Ann. Sci. Nat.' vol. vii. 1826, No. 1, pl. xi. figs. 5, 6; modèle, No. 59.

An arenaceous species distinguished by its compressed textularian commencement. Only the last chamber or so in this species is simple, and associated specimens are often found with only the textularian portion developed. It first made its appearance in Lower Tertiary times, and it was an abundant form on the London Clay sea floor, where Piccadilly now stands. In recent soundings the 'Challenger' obtained *B. capreolus* from 350 to 675 fathoms in the N. and S. Atlantic. Goës obtained it from the Caribbean Sea at 300 fathoms. *Tertiary. Recent.* (Plate 9, fig. G.)

SUB-GENUS *Siphogenerina*, SCHLUMBERGER.

Test either arenaceous or hyaline, and in no essential particular differing from *Bigenerina* externally, excepting in the position of the aperture; internally the uniserial chambers are connected by a siphon or tube.

EXAMPLE.—*B.* (*Siphogenerina*) *Schlumbergeri*, Millett, 'Journ. Roy. Micr. Soc.' 1900, p. 7, pl. i. figs. 5, 6.

The thin hyaline test of this species shows, when mounted in a transparent medium, the internal siphonate tube which connects the chambers of the later series. Millett records this species as being very common in the Malay Archipelago. (Plate 9, fig. H.)

GENUS *Pavonina*, D'ORBIGNY.

Early chambers small and textularian, later chambers broadly arched and uniserial, forming a fan-shaped test; aperture porous. *Recent.*

EXAMPLE.—*P. flabelliformis*, D'Orbigny, 'Ann. Sci. Nat.' vol. vii. 1826, p. 260, No. 1, pl. x. figs. 10, 11; modèle, No. 56.

This is the only species of the genus. It is a very handsome but rare form. The principal localities where it has been found are the West Indies, Madagascar, the Seychelle Islands, the Mauritius, Ceylon, Torres Strait, Malay Archipelago, Cocos Island, Admiralty Islands, Honolulu, and the coast of Korea. It inhabits fairly shallow water. (Plate 9, fig. I.)

GENUS *Spiroplecta*, EHRENBERG.

Early segments planospiral, later ones textularian, uniserial in the latest. *Lower Cretaceous to Recent.*

EXAMPLE.—*S. annectens*, Parker and Jones sp. (*Textularia*), 'Ann. and Mag. Nat. Hist.' ser. 3, vol. xi. 1863, p. 92, woodcut, fig. 1.

This elegant species is more regularly formed in the recent examples from Torres Strait and elsewhere than in the Gault specimens; the latter consist of fewer chambers, and there is also a tendency for the test to run into the uniserial condition in extra long specimens. *Lower Cretaceous to Recent.* (Plate 9, fig. J.)

GENUS *Gaudryina*, D'ORBIGNY.

Early segments triserial (verneuiline), later ones textularian; aperture either slitlike, as in *Textularia*, or an orifice situated on a short terminal neck. *L. Cretaceous to Recent.*

EXAMPLE.—*G. rugosa*, D'Orbigny, 'Mém. Soc. Géol. France,' vol. iv. 1840, p. 44, pl. iv. figs. 20, 21.

This species is distinguished by the acutely angular commencement of the test. Other species have the aboral end more rounded, and consequently the triserial beginning is more difficult to distinguish. The recent specimens are, as a rule, more coarsely arenaceous than those from the Cretaceous and Tertiary strata. It inhabits fairly shallow water. *Cretaceous to Recent.* (Plate 9, fig. K.)

GENUS *Valvulina*, D'ORBIGNY.

Test not dimorphous, spiral, typically triserial, with three segments or rarely more in each convolution; free or adherent; aperture partially covered by a valvular lip. *Carboniferous to Recent.*

EXAMPLE.—*V. palæotrochus*, Ehrenberg sp. (*Tetrataxis* and *Textilaria*), 'Mikrogeologie,' 1854, pl. xxxvii. par. xi. figs. A^1, 1–4.

The valvular aperture pertaining to the genus is well seen in the above species. In contour it resembles *V. conica*, but the test is largely calcareous, and the chambers more numerous and compressed. *Carboniferous.*

DIMORPHOUS (*Valvuline*) FORM.

GENUS *Clavulina*, D'ORBIGNY.

Early segments triserial (valvuline), later ones uniserial and rectilinear; test generally either cylindrical or trifacial; aperture valvular. *Eocene to Recent.*

EXAMPLE.—*C. communis*, D'Orbigny, 'Ann. Sci. Nat.' vol. vii. 1826, p. 268, No. 4.

This species is well distributed through the principal Tertiary strata. It is found in fairly deep water at the present day. Goës records it as occurring from 700 to 1,400 fathoms in the Pacific, and from 20 to 1,800 fathoms in the Caribbean Sea. *Eocene to Recent.* (Plate 9, figs. M, *m.*)

Sub-family 2. BULIMININÆ.

Test typically spiral, the weaker forms tending to become biserial; aperture oblique, twisted, and comma-shaped.

GENUS *Bulimina*, D'ORBIGNY.

Test spiral, elongate, more or less tapering; often triserial. *Jurassic to Recent.*

EXAMPLE.—*B. Presli*, Reuss, 'Verstein. böhm. Kreidef.' pt. i. 1845, p. 38, pl. xiii. fig. 72.

The Cretaceous deposits furnish us with some of the most characteristic species of the genus, and the present one, found in the Gault and Lower Chalk, is taken as a typical example. These forms are mainly arenaceous in shell-structure, and for this group Reuss proposed the name *Ataxophragmium*. It is difficult in practice, however, to separate the two series according to the structure of the shell, as they undoubtedly assume the different characters according to their surroundings. *Cretaceous.* (Plate 9, fig. N.)

GENUS *Virgulina*, D'ORBIGNY.

Test much elongated, more or less tapering; often triserial. *Lower Cretaceous to Recent.*

EXAMPLE.—*V. Schreibersiana*, Czjzek, 'Haidinger's naturw. Abhandl.' vol. ii. 1847, p. 147, pl. xiii. figs. 18–21.

This species shows the tendency of this particular type to assume the textularian arrangement of its segments. In deposits forming at the present time it is not restricted in its depth. *Miocene to Recent.* (Plate 9, fig. O.)

GENUS *Bifarina*, PARKER and JONES.

This is a dimorphous form, in which the earlier chambers are bulimine or bolivine and the later ones uniserial.

EXAMPLE.—*B. porrecta*, Brady sp. (*Bolivina*), 'Quart. Journ. Micr. Sci.' N.S. vol. xxi. 1881, p. 57; 'Rep. "Chall."' vol. ix. 1884, p. 418, pl. lii. fig. 22.

This is a thin hyaline-shelled species, with more or less coarse perforations in the shell-wall. It is usually rare in marine dredgings, but was found in abundance by Millett in his Malay samples. It is never found in very deep water. *Recent.* (Pl. 9, fig. P.)

GENUS *Bolivina*, D'ORBIGNY.

Test distinctly biserial, arrangement Textularian. *L. Cretaceous to Recent.*

EXAMPLE.—*B. textilarioides*, Reuss, 'Sitzungsb. d. k. Ak. Wiss. Wien,' vol. xlvi. 1862, p. 81, pl. x. fig. 1.

Of the regularly formed, few-chambered Bolivines this species may be regarded as a central type. The test is usually very finely arenaceous, especially the fossil representatives. Its geological distribution dates from the *Lower Cretaceous* period, and it appears in many *Tertiary* beds. *B. textilarioides* inhabits shallow or moderately deep water at the present day, and is but rarely found in depths greater than 900 or 1,000 fathoms. (Plate 9, fig. Q.)

GENUS *Mimosina*, MILLETT.

Test typically spiral, conical, or trochoid; chambers having a biserial or triserial arrangement. Aperture complex, consisting of two distinct orifices, one of them usually being a slit at the base of the inner wall of the final chamber, the other an opening varying in shape and situated near the apex of the chamber; the two orifices frequently connected internally by means of a bent tube or septum. Shell-wall cellular or spongy. *Recent.*

EXAMPLE.—*M. hystrix*, Millett, 'Journ. Roy. Micr. Soc.' 1900, p. 549, pl. iv. fig. 14.

The test of this species is triserial in the earlier part, afterwards becoming biserial. Double apertures, oval, with a bordered margin. Chambers armed each with a spine at the salient margin. Mr. Millett found this species in abundance in the Malay Archipelago. *Recent.* (Plate 9, fig. R.)

GENUS *Pleurostomella*, REUSS.

Test biserial; aperture large, usually arched or semicircular, with a notch at the middle of the lower edge, situated at the top of the nearly erect septal face of the last segment. *Cretaceous. Recent.*

EXAMPLE.—*P. subnodosa*, Reuss, 'Sitzungsb. d. k. Ak. Wiss. Wien,' vol. xl. 1860, p. 204, pl. viii. figs. 2*a*, *b*.

The features of this species are the cylindrical form, the short oblique sutures, and the rounded commencement. The communication between the chambers at their point of junction shows an attenuated spouted aperture, and this is covered over by the hoodlike prolongation formed by the succeeding chamber.

The fossil specimens are found in some abundance in the Gault and Chalk of N. Germany and Bohemia. Those from the recent soundings by the 'Challenger' occur at considerable depths—namely, 1,375 to 2,350 fathoms. *Cretaceous and Recent.* (Plate 9, fig. S.)

Sub-family 3. CASSIDULININÆ.

Test consisting of a *Textularia*-like series of alternating segments, more or less coiled upon itself.

GENUS *Cassidulina*, D'ORBIGNY.

Test biserial, folded on its long axis, and coiled more or less completely on itself; rarely dimorphous. *Lower Cretaceous to Recent.*

EXAMPLE.—*C. calabra*, Seguenza sp. (*Burseolina*), 'Formaz. Terz. Reggio,' 1879, p. 138, pl. xiii. figs. 7*a*, *b*.

Our present example is one of the more globose of the *Cassidulinæ*, in which the suture lines are flush with the surface of the shell. The test is usually of a polished texture. The fossil specimens came from Reggio, Calabria. As a recent form *Cassidulina calabra* has been recorded by Dr. H. B. Brady from Raine Islet, Torres Strait, 155 fathoms,

EXPLANATION OF PLATE 9.

FIG.

A. *Textularia rugosa*, Reuss sp. (after Brady). × 18.

B. *T. complanata*, Reuss sp. (after Chapman). × 16.

C. *Cuneolina pavonia*, D'Orbigny. *c* = peripheral face view, showing arrangement of suture lines. Magnified.

D. *Verneuilina spinulosa*, Reuss (after Brady). × 40.

E. *Tritaxia tricarinata*, Reuss (Gault specimen, after Chapman). × 24.

F. *Chrysalidina dimorpha*, Brady (after Millett). × 30.

G. *Bigenerina capreolus*, D'Orbigny (after Brady). × 10.

H. *B.* (*Siphogenerina*) *Schlumbergeri*, Millett. A specimen viewed by transmitted light, to show internal arrangement. × 50.

I. *Pavonina flabelliformis*, D'Orbigny (after Brady). × 30.

J. *Spiroplecta annectens*, Parker and Jones sp. (after Brady). × 40.

K. *Gaudryina rugosa*, D'Orbigny (Tertiary specimen, after Hantken). × 20.

L. *Valvulina palæotrochus*, Ehrenberg sp. Carboniferous limestone specimen (after Brady). × 24.

M. *Clavulina communis*, D'Orbigny (after Brady). M, lateral aspect, × 30; *m*, mouth of a larger specimen, × 22.

N. *Bulimina Presli*, Reuss (a Gault specimen, after Chapman). × 30.

O. *Virgulina Schreibersiana*, Czjzek (after Brady). × 60.

P. *Bifarina porrecta*, Brady sp. (after Millett). × 60.

Q. *Bolivina textilarioides*, Reuss (after Brady). × 55.

R. *Mimosina hystrix*, Millett. × 50.

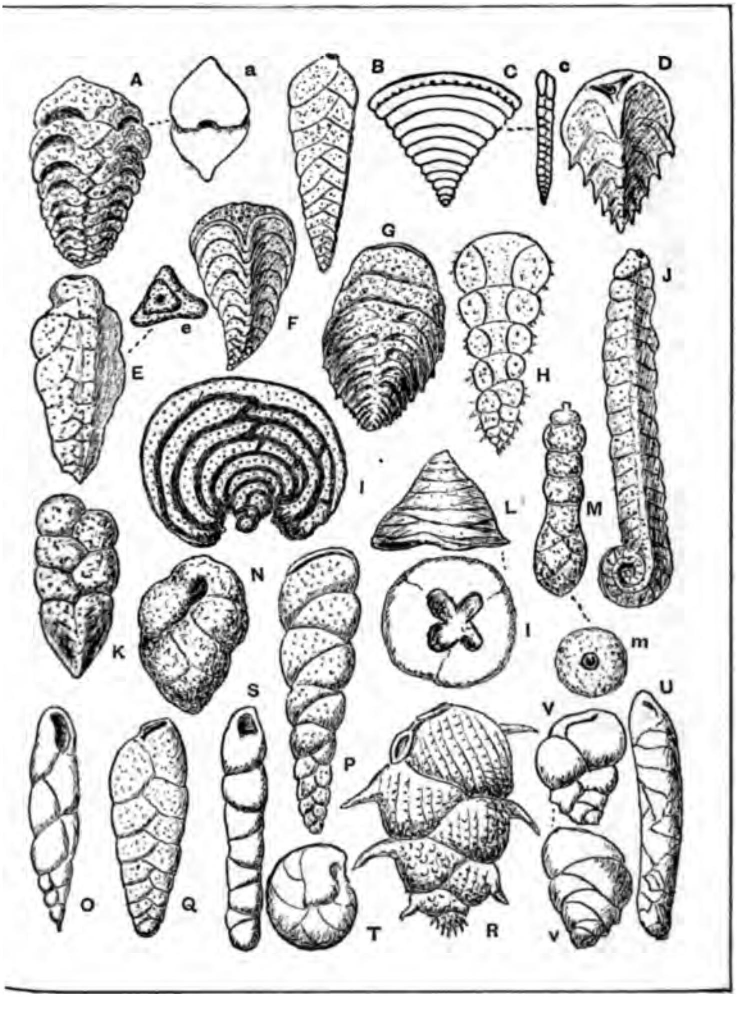
S. *Pleurostomella subnodosa*, Reuss (after Brady). × 37.

T. *Cassidulina calabra*, Seguenza (after Brady). × 37.

U. *C.* (*Orthoplecta*) *clavata*, Brady. × 56.

V. *Ehrenbergina pupa*, D'Orbigny (after Brady). × 42.

PLATE 9.



FAMILY V. TEXTULARIIDÆ.

and off Kandavu, Fiji Islands, 610 fathoms. The writer has recently met with it in the dredgings made by Prof. David round Funafuti, Ellice Islands, at 50 to 60 fathoms. *Upper Miocene and Recent.* (Plate 9, fig. T.)

SUB-GENUS *Orthoplecta*, BRADY.

In this genus there is no coiling of the test, but the segments are otherwise arranged, as in *Cassidulina.* It bears the same relation to the type-form as *Nodosaria* does to *Cristellaria. Recent.*

EXAMPLE.—*C.* (*Orthoplecta*) *clavata*, Brady, 'Rep. "Chall."' vol. ix. 1884, p. 432, pl. cxiii. fig. 9.

This interesting but rare form was originally found at Nares Harbour, Admiralty Islands, 17 fathoms. The writer has since obtained it from the Funafuti dredgings at 50 to 60 fathoms. *Recent.* (Plate 9, fig. U.)

GENUS *Ehrenbergina*, REUSS.

Test biserial, broad, arched on the dorsal side; general form that of an unfolded and uncoiled *Cassidulina. Lower Cretaceous to Recent.*

EXAMPLE.—*E. pupa*, D'Orbigny sp. (*Cassidulina*), 'Foram. Amér. Mérid.' 1839, p. 57, pl. vii. figs. 21–23.

This is a smooth-tested form of the above genus. Other species bear numerous spines as in *Mimosina*, notably *Ehrenbergina serrata* and *E. hystrix.* The author has recorded it from the Aptian beds of Surrey. *Lower Cretaceous to Recent.* (Plate 9, fig. V.)

CHAPTER XII

THE FAMILY CHEILOSTOMELLIDÆ

ONLY four genera are at present included in this family—namely, *Ellipsoidina*, *Cheilostomella*, *Seabrookia*, and *Allomorphina*.

The test is always calcareous, usually thin, and finely perforate. The segments, of which there are always more than one, are arranged either successively along an axis, placed alternately to one another at either end of the test, or grouped in cycles of three. The chambers are always more or less embracing. The aperture is either a curved or straight slit at the end or margin of the last segment.

Possibly the best known genus of this family is *Cheilostomella*, in which the chambers are placed alternately at either end of the long axis of the test. The separate segments are inflated, and the shell-walls of the chambers almost entirely conceal one another by their embracing growth.

In *Ellipsoidina* the chambers are entirely embracing, and a solid shelly column runs from the top of one chamber to the top of the succeeding one.

Allomorphina resembles *Cheilostomella* in the alternation of the position of the chambers, but the arrangement is in a cycle of three.

Lastly, in *Seabrookia*, a form which has been discovered within recent years, we have a modified *Cheilostomella*, in which the chambers are not so strongly inflated, and the aperture occupies a position at the apex of the shell instead of at the point of junction between the two chambers on one side of the test.

The members of this family were first recognised in the fossil state, and two of the genera, *Cheilostomella* and *Allomorphina*, formed the family Cryptostegia of Reuss.

GENUS *Ellipsoidina*, SEGUENZA.

Test uniaxial, segments oval, each springing from the base of the previous one and entirely enveloping it; aperture terminal. *Miocene to Post-Tertiary.*

EXAMPLE.—*E. ellipsoides*, var. *oblonga*, Seguenza, 'Eco Peloritano,' ser. 2, vol. v. 1859, fasc. 9 (13), pl. —, fig. 4 *a*, *b*; Brady, 'Quart. Journ. Geol. Soc.' vol. xliv. 1888, p. 5, pl. i. fig. 1.

This form, as well as the type species, was originally described from specimens out of the Miocene strata of Messina. Dr. Brady discovered, since then, other examples from the late Tertiary or post-Tertiary rocks of the Solomon Islands and from the 'Soapstone' of Fiji.

The section of the shell shown in fig. *a* of pl. 10 gives the position and appearance of the peculiar shelly pillar connected with the ends of each successive chamber. This genus has not been found in deposits actually forming at the present day. (Plate 10, figs. A, *a*.)

GENUS *Cheilostomella*, REUSS.

Segments oval, placed alternately at either end of the test. Aperture a curved slit, sometimes gaping, situated to one side, and at the junction of the penultimate and the final chamber. In recent specimens the test is thin and sparsely perforate; in fossil examples it is thicker and the perforations are difficult to make out on the polished shell surface. *Tertiary* (*Eocene*) *to Recent.*

EXAMPLE.—*C. ovoidea*, Reuss, 'Denkschr. d. k. Ak. Wiss. Wien,' vol. i. 1850, p. 380, pl. xlviii. figs. 12, *a–e.*

The figure of the recent example, reproduced from Mr. Millett's drawing, shows the arrangement of the chambers rather distinctly on the outer shell surface. The fossil specimens are as a rule more regularly ovoid in outline, save for the apertural portion of the shell, which is sometimes salient, or spouted. The oldest formation in which this species appears to have made its appearance is the *London Clay*; and in the material from Piccadilly the little egg-shaped tests are not uncommon. It is also a characteristic fossil in various *Oligocene* strata in North Germany and Austria, in the *Miocene* of Vienna, and the *Miocene* and *Pliocene* of Calabria. It is a well-distributed form in our existing seas. (Plate 10, fig. B.)

GENUS *Seabrookia*, BRADY.

Test free,. hyaline, perforate; composed of a number of chambers, each enclosing, partially or entirely, that preceding it; aperture terminal, alternately at each end of the test. *Recent.*

EXAMPLE.—*S. pellucida*, Brady, 'Journ. R. Micr. Soc.' 1890, p. 570, figs. 60, 1 *a–c*, 2; Wright, 'Proc. R. Irish Acad.' ser. 3, vol. i. 1891, p. 476, pl. xx. fig. 5; Millett, 'Journ. R. Micr. Soc.' 1901, p. 3, pl. i. fig. 4.

The test of this species is oval and depressed, with the two sides unequally convex, or sometimes almost plano-convex. The aboral end is rounded, the oral end somewhat drawn out. The peripheral edge is acute or subcarinate, and in large specimens serrate. The shell-wall is thin and transparent, smooth and finely perforate. Aperture terminal, slit-like with a thickened border.

The original specimens of the above form were obtained by Mr. Harris, of Cardiff, from Captain Seabrook, who dredged the material in the Java Seas off Cebu at 120 fathoms. Since then it has been obtained off Bermudas, 435 fathoms, and from the Malay Archipelago. (Plate 10, fig. C.)

GENUS *Allomorphina*, REUSS.

Segments alternating at three sides, so as to leave portions of two, in addition to the final one, exposed. *Up. Cretaceous. Recent.*

EXAMPLE.—*A. trigona*, Reuss, 'Denkschr. k. Ak. Wiss. Wien,' vol. i. 1850, p. 380, pl. xlviii. figs. 14 *a–e*.

Most, if not all, of the various so-called species of this genus may possibly belong to the one form named above. It occurs as a fossil in the *Chalk Marl* of Lemberg, in Galicia, and it is also distributed through various *Oligocene* and *Miocene* strata in Germany, Austria, and Poland. The living examples were found south of Japan, 345 fathoms, and off Tahiti, 620 fathoms. (Plate 10, fig. D.)

CHAPTER XIII

THE FAMILY LAGENIDÆ

E simplest type of shell in this family is the mono-
lamous *Lagena*, which is a flask-shaped, sub-
ıerical, or flattened chamber with a single orifice.
e various generic types comprised within this
ıily are the result of a successional growth or bud-
g of a series of lageniform chambers joined
ether in various ways and on certain definite plans.
ıen, for instance, the chambers are attached in a
niliform series by their ends, we have a form like
losaria; in a curved series, *Marginulina*; in a
ral series, *Cristellaria*; in alternating double or
le series, *Polymorphina*, and so on.

The type of shell-structure is the hyaline or vitre-
; the shell-wall is finely perforated and usually
ı. There is no trace of a double shell-wall or double
tum, as in the Rotaline and Nummuline types
shell-structure. But although the shell-wall is
ıple in its construction, it is often variously orna-
nted on the surface with hexagonal meshwork,
ong riblets, fine striæ, or series of punctations,
ich, however, do not show the laminar structure
n in the exogenous shell-growth of the Rotalines
l other forms of an advanced type.

Many of the genera belonging to the family LAGENIDÆ include a large number of known specific types, as *Nodosaria*, containing about 140, and *Cristellaria* about 160, well-defined forms. Their distribution as a group is very extensive throughout the fossiliferous strata of the earth's crust, and some of the earliest known types belong to this group of vitreous-shelled Foraminifera.

The sub-family LAGENINÆ includes only one genus, *Lagena*. This is typically monothalamous and presents a great variety of forms, some of which are flask-shaped, with an extended neck-like orifice (ectosolenian), or having an aperture at the end of an inverted neck, which is turned into the chamber and concealed by the shell (entosolenian). Other species, again, may have the flask-shaped form, but more or less compressed on two opposite faces, and with the normally circular aperture modified and represented by a slitlike orifice. In certain forms the orifice is triradiate, or even star-shaped (multiradiate). These various kinds of apertures are again met with in the succeeding groups of the NODOSARIINÆ and the POLYMORPHININÆ.

The genera which constitute the sub-family of the NODOSARIINÆ are very important, on account of their occurrence in considerable numbers and variety in the argillaceo-calcareous strata laid down in the seas of past geological times, such as those of the Lias, the Gault, the Chalk, and certain Tertiary beds. At the present day these Nodosarine forms are met with in a few localities in tolerable abundance; but they seem to have flourished best during the Mesozoic and Tertiary periods.

The Nodosarines are characterised by a plan of successional growth of lageniform chambers joined in a moniliform series and variously modified. In the next sub-family, the POLYMORPHININÆ, the chambers are arranged side by side, or wound spirally round a common axis of growth.

The fourth sub-family, the RAMULININÆ, includes two genera, which in their early stages show affinities towards *Polymorphina*, but which afterwards grow erratically and consist essentially of branching, tubular chambers.

Sub-family 1. LAGENINÆ.

Test monothalamous, hyaline, finely perforate.

GENUS *Lagena*, WALKER and BOYS.

A single-chambered shell, with either an ectosolenian or an entosolenian orifice; sometimes distomous apertures at both ends. Shell-surface either smooth or variously decorated with striæ, punctations, ridges, or polygonal meshwork. *Cambrian to Recent.*

EXAMPLES.—*L. sulcata*, Walker and Jacob, Adams's 'Essays,' Kanmacher's ed., 1798, p. 634, pl. xiv. fig. 5.

The present example affords one a good idea of the typical ectosolenian and flask-shaped *Lagena*. This species and its allies are often met with in the shallow-water sands and dredgings off the coasts of the British Islands and elsewhere. The geographical distribution of this particular form is very extensive in the seas of the present day. It is not confined to shallow water, but has a range from the littoral zone down to 2,750 fathoms. *Silurian to Recent.* (Plate 10, fig. E.)

L. marginata, Walker and Boys, 'Test. Min.' 1784, p. 2, pl. i. fig. 7.

Of the compressed varieties of *Lagena* with an entosolenian orifice this present form may be considered typical. The flange-like border or keel varies greatly in width, and is sometimes so developed that it forms an encircling wing.

L. marginata, like the preceding, has an extensive geographical distribution; and is found at all depths from shallow water down to 3,125 fathoms. *Upper Cretaceous (Gault) to Recent.* (Plate 10, fig. F.)

SUBFAMILY 2. NODOSARINAE.

Test polythalamous; straight, arcuate, or planospiral.

GENUS NODOSARIA, LAMARCK.

Test straight or curved, circular in transverse section; aperture typically central. *Cambrian to Recent.*

EXAMPLE.—*N.* [illegible], Reuss, 'Verstein. böhm. Kreide,' pt. i. 1845, p. [illegible], pl. [illegible] figs. 1–3.

Many of the true forms of *Nodosaria* are variously striated and sulcate, and the present example falls into this group, in which the central type is *N. raphanus* of Linné. *N. Zippei* is a characteristic cretaceous fossil, occurring in the Gault and Chalk of England and Bohemia. It is well separated from the type form *N. raphanus* by the strongly inflated chambers and the small number of the salient vertical costæ. *Cretaceous.* (Plate 10, fig. I.)

Two other examples are now given of what are often regarded as sub-generic modifications of *Nodosaria*—namely, *Glandulina*, in which the test is short and almost lageniform in outline, the earlier chambers being vertically compressed into a shorter space than is usual in *Nodosaria*, and with the later chamber or chambers much more spacious and inflated; and *Dentalina*, which is a curved nodosarine form, often gracefully tapering towards the aboral extremity.

N. (*Glandulina*) *lævigata*, D'Orbigny, 'Ann. Sci. Nat.' vol. vii. 1826, p. 252, pl. x. figs. 1–3.

This species has a fairly wide range in the fossiliferous formation, since it first appears in the Lias of Chellaston; and it has been recorded under various synonyms, from successive strata of later date. As *N.* (*G.*) *abbreviata* it was described from the London Clay of Piccadilly, and from the Miocene of Transylvania. This species is well distributed in modern seas. *Lias to Recent.* (Plate 10, fig. G.)

N. (*Dentalina*) *Adolphina*, D'Orbigny, 'Foram. Foss. Vienne,' 1846, p. 51, pl. ii. figs. 18–20.

This pretty little species is found in some abundance in various Tertiary deposits, such as the London Clay (Eocene), the '*Clavulina*' beds of Budapest (Eocene), the Miocene of the Vienna basin, and the Pliocene of Kar-Nicobar. It is also known from recent soundings, but it is very rare, and apparently confined to the Indian Ocean. *Tertiary to Recent.* (Plate 10, fig. H.)

GENUS *Lingulina*, D'ORBIGNY.

Test straight, compressed; aperture typically a narrow fissure. *Permian to Recent.*

EXAMPLE.—*L. semiornata*, Reuss, 'Sitz. d. k. Ak. Wiss. Wien,' vol. xlvi. pt. i. 1862, p. 91, pl. xii. figs. 11 *a*, *b*.

The chief features of the genus are well seen in this example; the compression of the nodosarine chambers affects the oral aperture, which is thereby modified as a terminal slit.

L. semiornata is almost confined to the Gault formation, and it was from a specimen of English Gault clay sent to Prof. von Reuss by Prof. Rupert Jones that the original examples were described. It has lately been met with in the Aptian beds of Surrey. *Cretaceous.* (Plate 10, fig. J.)

GENUS *Frondicularia*, DEFRANCE.

Test compressed or complanate, segments shaped like an inverted V, equitant; primordial chamber distinct. *Permian to Recent.*

EXAMPLE.—*F. Parkeri*, Reuss, 'Sitzungsb. d. k.

Ak. Wiss. Wien,' vol. xlvi. pt. i. 1862, p. 91, pl. xii. figs. 7*a*, *b*.

This genus was particularly abundant in *Cretaceous* seas; the above example is a typical one from the Gault, and it also extends its range into the Chalk. (Plate 10, fig. K.)

GENUS *Rhabdogonium*, REUSS.

Test straight or slightly curved, angular or subcarinate, usually three- or four-sided. *Lias to Recent.*

EXAMPLE.—*R. tricarinatum*, D'Orbigny sp. (*Vaginulina*), 'Ann. Sci. Nat.' vol. vii. 1826, p. 258, No. 4; 'Modèle,' No. 4.

The typical examples of the above species are confined to Tertiary strata, where it has a wide distribution. A variety (*acutangulum*, Reuss) has been described from Lower Cretaceous beds of Aptian age in Germany, and it also occurs in the Gault of England.

As a recent form it is common in the North Atlantic from shallow water down to 1,360 fathoms; and it also occurs in the Mediterranean Sea and the Pacific Ocean. Silvestri's specimen (see figure) came from the Pliocene of Sienna. *Tertiary to Recent.* (Plate 10, figs. L, *l*.)

GENUS *Marginulina*, D'ORBIGNY.

Test elongate, curved; segments circular in section; aperture marginal.—*Cambrian to Recent.*

EXAMPLE.—*M. raricosta*, D'Orbigny, 'Mém. Soc.

Géol. France,' ser. 1, vol. iv. 1840, p. 51, pl. i. fig. 25.

The marginuline characters are well seen in this species. The test in this genus is frequently ribbed, as in the *raphanus* type of *Nodosaria*, whilst the smooth forms are comparable with the *Dentalinæ* of the *communis* section.

M. raricosta was obtained by D'Orbigny from the *Chalk* of Meudon, France. (Plate 10, fig. M.)

GENUS *Vaginulina*, D'ORBIGNY.

Test elongate, compressed or complanate; septation oblique; aperture marginal. *Lias to Recent.*

EXAMPLE.—*V. recta*, Reuss, 'Sitzungsb. d. k. Ak. Wiss. Wien,' vol. xlvi. Abth. 1, 1862, p. 48, pl. iii. figs. 14, 15 *a*, *b*.

The Jurassic and Cretaceous species of *Vaginulina* are usually costate, and the above is a typical example of such. The recent examples of the genus are generally of the smooth type of shell. *V. recta* was found by Reuss in the Gault Clays of North Germany, and in that at Folkestone, whilst Berthelin noted it from the equivalent strata in France (at Montcley). It is also of frequent occurrence in the Red Chalk of Speeton. Higher in the series it occurs in the Chalk Marl of Folkestone and elsewhere. *Cretaceous.* (Plate 10, fig. N.)

GENUS *Rimulina*, D'ORBIGNY.

Test resembling a thick, somewhat rounded, *Vaginulina*; septation very oblique; aperture a long slit down the ventral face of the final segment; chambers few. *Recent.*

EXAMPLE.—*R. glabra*, D'Orbigny, 'Foraminif. Foss. Vienne,' 1846, p. 63, pl. xxi. figs. 5, 6.

This form is not often met with, and may possibly be only an aberrant variety of *Vaginulina*. D'Orbigny's specimen was obtained from the Adriatic. *Recent.* (Plate 10, fig. O.)

GENUS *Cristellaria*, LAMARCK.

Test planospiral in part or entirely; complanate, lenticular, crozier-shaped or ensiform (elongate). *Upper Cambrian to Recent.*

EXAMPLES.—*C. crepidula*, Fichtel and Moll sp. (*Nautilus*), 'Test. Micr.' 1798, p. 107, pl. 19, *g–i.*

This is a complanate and somewhat elongate form of the genus. It is common in fossiliferous strata dating from the Lias, and at the present day it is found in comparatively shallow water. *Lias to Recent.* (Plate 10, fig. P.)

C. budensis, Hantken sp. (*Robulina*), 'Mitth. a. d. Jahrb. k. ungar. Geol. Anstalt,' vol. iv. 1875 (1881), p. 58, pl. vii. fig. 1.

The above species is a complanate, partially evolute form of *Cristellaria*, in which the primordial chamber is just visible in the centre of the spiral shell. The margin is carinate or sharply flanged, as in the central type *C. cultrata*, and of which there are many varieties. *C. budensis* was obtained from the *Clavulina-szabói* beds of Budapest, of *Eocene* age. (Plate 10, fig. Q.)

EXPLANATION OF PLATE 10.

A, a. *Ellipsoidina ellipsoides*, var. *oblonga*, Seguenza: *a*, section of test showing internal arrangement of chambers (after Brady). × 30.

B. *Chilostomella ovoidea*, Reuss (after Millett). × 50.

C. *Seabrookia pellucida*, Brady: test as it appears by transmitted light. × 100.

D. *Allomorphina trigona*, Reuss (after Brady). × 55.

E. *Lagena sulcata*, Walker and Jacob (after Brady). × 40.

F. *L. marginata*, Walker and Boys (after Brady). × 30.

G. *Nodosaria (Glandulina) laevigata*, D'Orbigny (after Neugeboren). × 20.

H. *N. (Dentalina) Adolphina*, D'Orbigny (after Sherborn and Chapman). × 20.

I. *N. Zippei*, Reuss (after Chapman). × 30.

J, *j*. *Lingulina semiornata*, Reuss: *j*, oral aspect. × 60.

K. *Frondicularia Parkeri*, Reuss (after Chapman). × 30.

L, *l*. *Rhabdogonium tricarinatum*, D'Orbigny sp. (after Silvester): *l*, oral aspect. × 50.

M. *Marginulina raricosta*, D'Orbigny. Magnified.

N. *Vaginulina recta*, Reuss (after Berthelin). × 50.

O. *Rimulina glabra*, D'Orbigny.

P. *Cristellaria crepidula*, Fichtel and Moll sp. Magnified.

Q. *C. budensis*, Hantken sp. × 10.

R. *Amphicoryne parasitica*, Schlumberger. × 30.

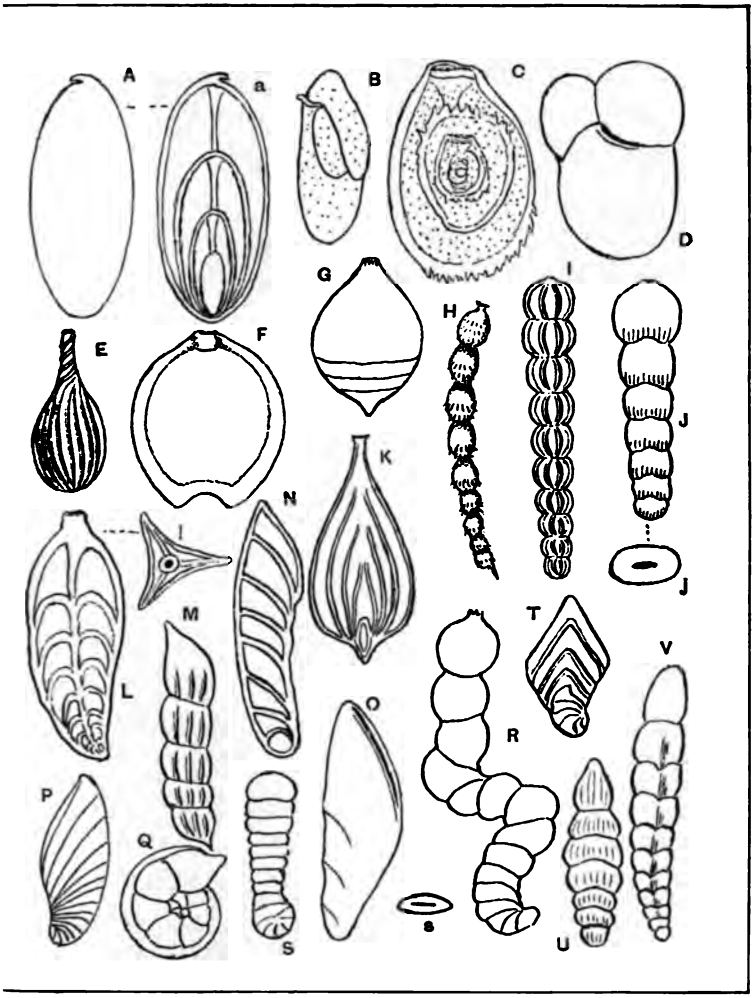
S, *s*. *Lingulinopsis bohemica*, Reuss: *s*, oral aspect.

T. *Flabellina rugosa*, D'Orbigny (after Reuss). × 16.

U. *Amphimorphina striata*, Reuss. Magnified.

V. *Dentalinopsis subtriquetra*, Reuss. Magnified.

PLATE 10.



Family VI. CHEILOSTOMELLIDÆ; and

Family VII. LAGENIDÆ.

DIMORPHOUS GENERA.

GENUS *Amphicoryne*, SCHLUMBERGER.

Early chambers Cristellarian, later ones Nodosarian. *Recent.*

EXAMPLE.—*A. parasitica*, Schlumberger, 'Mém. Soc. Zool. France,' vol. v. 1892, p. 197, pl. viii. figs. 10–12.

This is an intermediate form between *Cristellaria* and *Dentalina*. The commencement of the shell resembles *Cristellaria crepidula*. The original examples were dredged by the Prince of Monaco in the Azores at 71 fathoms. (Plate 10, fig. R.)

GENUS *Lingulinopsis*, REUSS.

Early chambers Cristellarian, later ones Linguline.

EXAMPLE.—*L. bohemica*, Reuss; Reuss's 'Model,' No. 30, 1865.

A compressed marginuline form with the aperture slitlike and terminal.

Reuss's specimen came from the Chalk of Bohemia. (Plate 10, fig. S.)

GENUS *Flabellina*, D'ORBIGNY.

Early chambers Cristellarian, later ones Frondicularian. *Lias to Recent.*

EXAMPLE.—*F. rugosa*, D'Orbigny, 'Mém. Soc. Géol. France,' vol. iv. 1840, p. 23, pl. ii. figs. 4, 5, and 7.

This is a typical example of the peculiar dimorphous form referred to as ***Flabellina.*** It is almost essentially a Cretaceous genus, but it occurs sparingly in certain Tertiary deposits, and aberrant forms of *Frondicularia* are still found in the living condition which resemble this dimorphic type of organism. The present species, ***F. rugosa,*** is well known from Cretaceous strata. (Plate 10, fig. T.)

GENUS *Amphimorphina*, NEUGEBOREN.

Early chambers Frondicularian, later ones Nodosarian. *Cretaceous and Tertiary.*

EXAMPLE.—*A. striata*, Reuss, 'Sitzungsb. d. k. Ak. Wiss. Wien,' vol. xlvi. Abth. 1, 1862 (1863), p. 57, pl. v. fig. 5.

Reuss's example was obtained from the Upper Hils Clay of Northern Germany. The only other known species, *A. Haueriana*, Neugeboren described from the Miocene of Transylvania, and Karrer has recorded it from the Miocene of the Vienna Basin. (Plate 10, fig. U.)

GENUS *Dentalinopsis*, REUSS.

Early chambers Rhabdogonian, later ones Nodosarian (Dentaline). *Lower Cretaceous.*

EXAMPLE.—*D. subtriquetra*, Reuss, 'Sitzungsb. d. k. Ak. Wiss. Wien,' vol. xlvi. Abth. 1, 1862 (1863), p. 57, pl. v. figs. 6 *a*, *b*.

At the earlier part of the shell this form resembles a triangular *Dentalina*. Reuss found his specimens in the Middle Hils Clay of North Germany (Aptian stage). (Plate 10, fig. V.)

Sub-family 3. POLYMORPHININÆ.

Segments arranged spirally or irregularly around the long axis; rarely biserial and alternate.

GENUS *Polymorphina*, D'ORBIGNY.

Segments biserial or triserial or irregularly spiral. Aperture radiate. *Trias to Recent.*

EXAMPLE.—*P. gibba*, D'Orbigny, 'Ann. Sci. Nat.' vol. vii. 1826, p. 266, No. 20; — Modèle, No. 63.

This species has an almost globular test, generally with three chambers visible on one of the surfaces. The suture lines are only faintly marked on the shell-surface.

P. gibba first makes its appearance as a fossil in beds of Oolitic age, and it is found in all succeeding formations to the present day. It is a well-distributed species both geographically and bathymetrically. (Plate 11, fig. A.)

DIMORPHOUS FORM.

GENUS *Dimorphina*, D'ORBIGNY.

Early chambers Polymorphine, later ones Nodosarian.

EXAMPLE.—*D. tuberosa*, D'Orbigny, 'Ann. Sci. Nat.' vol. vii. 1826, p. 264, No. 1; Modèle, No. 60.

The shell of this species is elongate, subcylindrical, and straight. Anterior end acuminate; posterior obtuse and rounded. Early alternating chambers vary in number; later, uniserial chambers two to six in number, more or less inflated. Surface smooth. The fossil specimens of the above form were found in the Tertiary beds of Italy, Spain, of the Vienna Basin, and East Anglia. It is also noted from the Mediterranean at depths not exceeding 100 fathoms. (Plate 11, fig. B.)

GENUS *Uvigerina*, D'ORBIGNY.

Segments arranged in a more or less regular spire round the long axis of the shell, rarely biserial. Aperture single, usually surrounded by a phialine lip; often forming a prolonged terminal tube.

In this genus the surface of the test is frequently ornamented either with striæ, costæ, prickles, or spines. *Eocene to Recent.*

EXAMPLE.—*U. pygmæa*, D'Orbigny, 'Ann. Sci. Nat.' vol. vii. 1826, p. 269, pl. xii. figs. 8, 9; Modèle, No. 67.

This species is one of the strong-ribbed modifications, with a broadly ovate test. As a fossil it is common in all the later Tertiary (Neogene) deposits. In modern seas it is a well-distributed species, and ranges from shallow water to 2,600 fathoms. Goës's specimens came from the west coast of Scandinavia at depths of 11 to 49 fathoms. *Miocene to Recent.* (Plate 11, fig. C.)

DIMORPHOUS FORM.

GENUS *Sagraina*, D'ORBIGNY, emended by PARKER and JONES.

Early segments Uvigerine, later ones Nodosarian. *Eocene to Recent.*

EXAMPLE.—*S. striata*, Schwager (*Dimorphina*), 'Novara-Exped., geol. Theil,' vol. ii. 1866, p. 251, pl. vii. fig. 99.

The typical Uvigerine commencement is distinctly seen in this species.

As a recent form *S. striata* seems confined to tropical areas, and ranges in its depth from quite shallow water to 350 fathoms. The fossil examples were obtained from the Eocene beds of Hungary, the Miocene of Malta, and the Pliocene of Kar Nicobar. *Eocene to Recent.* (Plate 11, fig. D.)

Sub-family 4. RAMULININÆ.

Test commencing with an imperfectly segmented series of chambers, sometimes resembling to a certain extent the simpler forms of *Polymorphina*, to which genus the present group bears some affinities; afterwards branching irregularly and taking the form of subspherical chambers united by long and slender stoloniferous tubes, or a series of pyriform chambers with or without intermediate stoloniferous tubes.

GENUS *Ramulina*, RUPERT JONES.

Test branching, composed of spherical or pyriform chambers connected by long stoloniferous tubes. *Jurassic to Recent.*

EXAMPLE.—*R. globulifera*, Brady.

This species, which may be taken as typical of the free-growing forms, is distinguished by its branching test, composed of irregular subglobular chambers, connected by slender curved or straight stoloniferous tubes, and which radiate from the chambers. Segments internally septate, but only in an imperfect manner. Texture hyaline, finely perforate. Surface of test hispid or aculeate, but not so coarsely as in the cretaceous species *R. aculeata.*

R. globulifera has been recorded as a fossil under various names from the Middle Jurassic of Poland and Switzerland, the Aptian beds of Surrey, the Gault of France and England, and from various Tertiary beds, as the London Clay, and the Pliocene of Italy. It occurs at moderate depths in the seas of the present day. *Jurassic to Recent.* (Plate 11, fig. E.)

GENUS *Vitriwebbina*, CHAPMAN.

Test adherent, consisting of a series of hemispherical or elliptical chambers, gradually increasing in size and usually arranged in a curvilinear manner. The commencing segment sometimes exhibits a polymorphine septation. Shell finely perforate, translucent or dull. Surface of the test smooth or minutely tuberculate. Aperture a simple crescentic space situated between the inferior margin of the shell and its object of attachment, at the termination of the last chamber. *Cretaceous.*

EXAMPLE.—*V. lævis*, Sollas sp. (*Webbina*), 'Geol. Mag.' Dec. 2, vol. iv. 1877, pp. 103, 104, pl. vi. figs. 1–3.

The test of this species is smooth and glossy in appearance. The segments, which are hemispherical or ovoid, are joined to form a short series; adherent to fragments of rolled phosphatic chips or shells, and usually found in hollows or recesses in such fragments, as if for protection.

V. lævis is found sparingly in various Cretaceous beds, as the Marl of New Jersey, the Gault of Folkestone, the Greensand of Cambridge, and the Chalk-marl of Kent. (Plate 11, fig. F.)

CHAPTER XIV

THE FAMILY GLOBIGERINIDÆ

THE group of Foraminifera which constitutes the above family is not, like most of the preceding divisions, separable into a closely connected and progressive series of forms, but the various genera have many features in common with the whole group, and the phenomena of isomorphism amongst species of different genera is often very marked. The greater number of the members of the GLOBIGERINIDÆ are pelagic or surface-living organisms.

The salient characters of the group are a test which is never attached; a perforate shell-wall very variable in thickness even in the same genus; chambers few, inflated, arranged spirally; aperture single or multiple, conspicuous. There is no supplementary skeleton nor canal system.

With regard to the isomorphism of the various species, mention may be made of *Globigerina bulloides* with *Candeina nitida*, *Globigerina conglobata* with *Sphaeroidina bulloides* and *Pullenia obliquiloculata* and *Globigerina æquilateralis* with *Hastigerina pelagica* and *Pullenia quinqueloba*. The genus *Globigerina* has some isomorphous types corresponding even with certain forms of the next family, the ROTALIIDÆ, as *Globigerina cretacea* and *Discorbina rugosa*.

GENUS *Globigerina*, D'ORBIGNY.

Test coarsely perforate; trochoid, rotaliform, or symmetrically planospiral; segments few, inflated; pelagic specimens spinous. *Cambrian to Recent.*

EXAMPLES.—*G. bulloides*, D'Orbigny, 'Ann. Sci. Nat.' vol. vii. 1826, p. 277, No. 1; 'Modèles,' No. 17 and No. 76.

The size of the test in this species varies greatly. The British specimens are usually one-fifth the diameter of good typical examples from mid-ocean. It is found in every sea, and certain deep-sea deposits are often chiefly composed of the shells of this type-form. Undoubted examples are recorded from strata of Lower Cretaceous age, and it is well distributed throughout almost all Tertiary deposits up to the present time. The Pliocene specimens more nearly approach the recent examples in point of size.

Fig. H shows the appearance of the test when obtained from bottom oceanic deposits. (Plate 11, figs. H, *h*.)

G. bulloides, var. *triloba*, Reuss, 'Denkschr. d. k. Akad. Wiss. Wien,' vol. i. 1849, p. 374, pl. xlvii. fig. 11 *a–e*.

This is a three-chambered variety with an almost invisible spire, which is found associated with the typical *G. bulloides*. Fig. G represents a surface specimen of this variety, in which the slender spines are still attached. (Plate 11, fig. G.)

GENUS *Orbulina*, D'ORBIGNY.

Test having the external form of a single spherical chamber with two sorts of perforations, large and small; pelagic specimens often with a thin shell-wall and radiating spines.

EXAMPLE.—*O. universa*, D'Orbigny, 'Foram. Cuba,' 1839, p. 3, pl. i. fig. 1.

This consists of a spherical chamber, sometimes modified by showing a bilobation or protuberance on one side. Usually the interior, especially in the thin-shelled pelagic forms, contains a small *Globigerina*-like series of chambers fastened to one side of the test. It has been considered by some Rhizopodists that this genus is only of quasi-generic value, and that it is a reproductive stage of the typical *Globigerina*. It is a very common form in all surface dredgings, and the tests often constitute a large proportion of the *Globigerina* oozes accumulating at the present time. (*? Cambrian.*) *Lias to Recent.* (Plate 11, fig. I.)

GENUS *Hastigerina*, WYVILLE THOMSON.

Test regularly nautiloid, involute; shell-wall thin, finely perforated; armed with long serrate spines. Aperture a large crescentiform opening at the base of the last chamber. Essentially pelagic. *Recent.*

EXAMPLE.—*H. pelagica*, D'Orbigny sp. (*Nonionina*), 'Foram. Amér. Mérid.' 1839, p. 27, pl. iii. figs. 13, 14.

This is a thin-shelled form, consisting of a nautiloid spire, subglobular, or compressed bilaterally, with umbilical depressions, and a lobulated margin. The specimens ordinarily obtained from deep-sea deposits are imperfect, showing only the bases of the spines which in the living condition beset the surface of the test. Sir John Murray, in referring to the appearance of this interesting form when alive, says: 'At times calcareous Foraminifera occur in vast numbers on the surface, and with a bottle can be picked up from a boat. In one specimen thus procured the sarcode of the animal was found thrown out into bubble-like extensions between the spines of the shell, and over these expansions of the sarcode and along the spines the pseudopodia moved freely and rapidly.'

H. pelagica is by no means a common form in ordinary dredgings, but from surface dredgings specimens are often procured in considerable numbers. (Plate 11, fig. J.)

GENUS *Pullenia*, PARKER and JONES.

Test regularly or obliquely nautiloid and involute; segments only slightly ventricose. Shell-wall very finely perforated; aperture a long curved slit close to the line of union of the last segment with the previous convolution. *Cretaceous to Recent.*

EXAMPLE.—*P. sphæroides*, D'Orbigny sp. (*Nonionina*), 'Ann. Sci. Nat.' vol. vii. 1826, p. 293, No. 1; 'Modèle,' No. 43.

The shell is subglobular, with a smooth or even polished surface. The perforations of the test are very minute ; Dr. Brady gives as their approximate diameter $\frac{1}{25000}$ of an inch (0·001 mm.) It first makes its appearance as a fossil in the Chalk-marl, and continues through many formations of succeeding age to the present time. It is now a widely distributed form in deep-sea deposits. (Plate 11, figs. K, *k*.)

GENUS *Sphæroidina*, D'ORBIGNY.

Segments few, coiled so as to form a nearly globular shell ; aperture arched ; sometimes partially closed with a valvular tongue. *Cretaceous to Recent.*

EXAMPLE.—*S. bulloides*, D'Orbigny, 'Ann. Sci. Nat.' vol. vii. 1826, p. 267, No. 1 ; 'Modèle,' No. 65.

The test of this species is nearly spherical, but somewhat flattened at the umbilical axis. The chambers to a certain extent embrace the earlier part of the shell, so that only the last three or four chambers--practically the last convolution—are visible.

In the fossil state *S. bulloides* first makes its appearance in the Gault of Folkestone. It has also been found in the Chalk of Meudon, France, and of the Island of Rügen, and it is a well-known and widely distributed species in the faunas of the Tertiary beds of Europe generally. At the present time it is found from the coast of Norway to the Southern and Indian Oceans, and at almost every depth where Foraminifera are obtained. It has not yet been ascertained whether this species is pelagic. *Cretaceous to Recent.* (Plate 11, fig. L.)

GENUS *Candeina*, D'ORBIGNY.

Test trochoid; segments inflated; shell-wall thin, finely perforated. Apertures consisting of rows of pores along the septal lines. *Recent.*

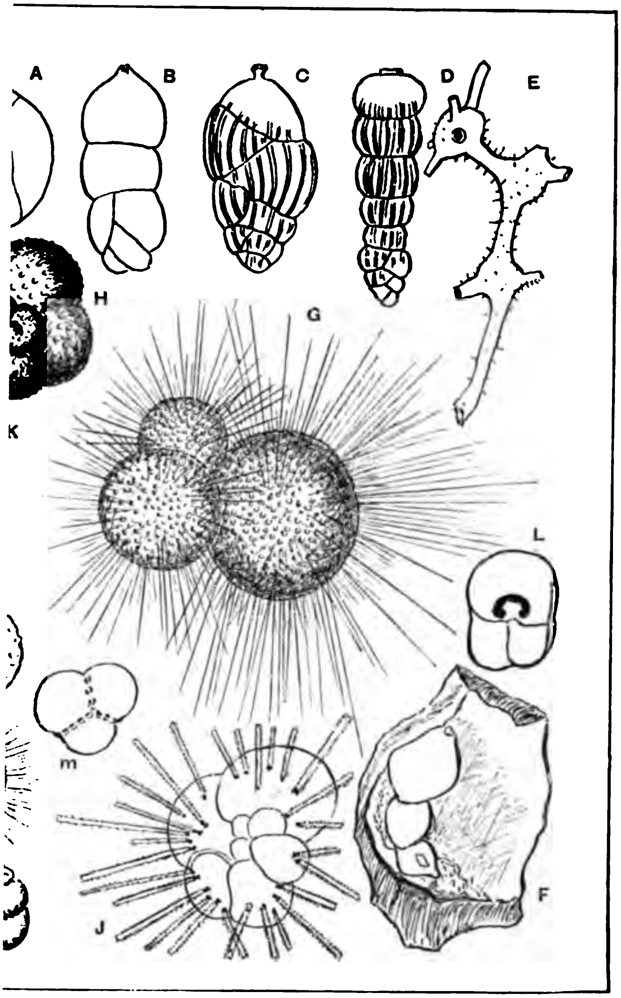
EXAMPLE.—*C. nitida*, D'Orbigny, 'Foram. Cuba,' 1839, p. 111, pl. ii. figs. 27, 28.

This pelagic form is widely diffused, but is by no means common. It has occurred in the N. Atlantic, to the S. of the Canaries, and in the shore sands of Cuba and Jamaica. It has also been found in the S. Atlantic and in the N. and S. Pacific Oceans. At Funafuti, in the S. Pacific, it has lately been found in dredgings from depths of 50 to 60 and 200 fathoms. (Plate 11, figs. M, *m*.)

EXPLANATION OF PLATE 11.

FIG.
A. *Polymorphina gibba*, D'Orbigny (after Goës). × 16.
B. *Dimorphina tuberosa*, D'Orbigny. × 25.
C. *Uvigerina pygmæa*, D'Orbigny (after Goës). × 12.
D. *Sagraina striata*, Schwager (after Brady). × 30.
E. *Ramulina globulifera*, Brady. × 35.
F. *Vitriwebbina lævis*, Sollas sp. × 17.
G. *Globigerina bulloides*, D'Orbigny, var. *triloba*, Reuss; surfac specimen, with spines. × 50.
H, *h*. *G. bulloides*, D'Orbigny: *h*, oral aspect of another specimen. · 4
I. *Orbulina universa*, D'Orbigny: pelagic specimen. × 25.
J. *Hastigerina pelagica*, Wyville Thomson. × 27.
K, *k*. *Pullenia sphæroides*, D'Orbigny sp.: *k*, oral aspect. × 35.
L. *Sphæroidina bulloides*, D'Orbigny. × 14.
M, *m*. *Candeina nitida*, D'Orbigny: *m*, inferior surface. × 18.

PLATE 11.



AMILY VII. LAGENIDÆ (*concluded*); AND
FAMILY VIII. GLOBIGERINIDÆ.

CHAPTER XV

THE FAMILY ROTALIIDÆ

shell-structure of the Foraminifera constituting
Family ROTALIIDÆ is essentially calcareous, hya-
and perforate. The tests are sometimes found
rent to other objects, but are more usually
Their chief character is the rotaline or spiral
of the shell; and the coil is generally asym-
ical. To this method of growth there are some
ptions, as in the acervuline genera, like *Planor-*
na and *Gypsina*, but which, however, show their
ionship to the more typical members of the
ly by their rotaline contour in the earlier stages
rowth, occasionally only in those chambers formed
e embryonic condition.

The typical appearance of a Rotaline form is a
l series of chambers so arranged that on one
, the superior, we have all the chambers visible;
st on the other, the inferior face, only those of
last whorl are seen. The aperture is usually
ated on this inferior surface.

The more advanced types of shell-structure in
family consist in the presence of a double wall
he chambers. There is sometimes a redundant
th of shell-structure also present, which chiefly

serves to strengthen or otherwise fortify the shell, called the supplemental skeleton, and these extra layers and the shell-wall proper are frequently traversed by a system of interseptal canals.

In the SPIRILLININÆ we have an example of perhaps the simplest type of shell, consisting as it does of an open and coiled tube without any septation. In the conical modifications of this generic group we seem to see the relationship between this type and the genus *Patellina* of the next sub-family.

In the ROTALIINÆ the typical *Patellina* is an irregularly coiled shell forming a cone, in which the spiral portion at the commencement is sometimes non-septate, but this is immediately succeeded by a septate, or imperfectly septate, tube. The genus *Cymbalopora* proceeds a stage farther; the chambers are at first spirally arranged, but afterwards grow in a concentric manner; and the chambers have an oblique septation somewhat similar to that seen in the later whorls of *Patellina*. On the other hand *Cymbalopora*, especially the outspread modifications, shows some relationship with *Planorbulina*. The typical rotaline shells are comprised in the genera *Discorbina*, *Truncatulina*, *Pulvinulina*, and *Rotalia*; and these, being mainly distinguished by the nature of their shell-structure, present an interesting series of isomorphous species.

In the apparently aberrant genera *Rupertia* and *Carpenteria* the affinity to the Rotalines proper may be seen in their earlier chambers, which are arranged as in *Truncatulina*. The sub-family of the TINO-

PORINÆ embrace a number of somewhat aberrant forms, which, although in their earliest chambers distinctly rotaline, are sooner or later modified in their plan of growth, and increase in size by the addition of numerous chamberlets, somewhat irregularly disposed in relation to one another (acervuline).

Sub-family 1. SPIRILLININÆ.

Test spiral, non-septate.

GENUS *Spirillina*, EHRENBERG.

Test a complanate, plano-spiral, or conoidal non-septate tube; free or attached. *Upper Cambrian to Recent.*

EXAMPLE.—*S. vivipara*, Ehrenberg, 'Abhandl. k. Akad. Wiss.' Berlin, 1841, p. 442, pl. iii. fig. 41.

This is a delicate little species, usually free but sometimes found attached to marine objects, as seaweed. It is very extensively distributed, and occurs usually in fine muddy deposits of less than 150 fathoms. As a fossil it has been noted from various strata dating from Miocene times. *Miocene to Recent.* (Plate 12, fig. A.)

Sub-family 2. ROTALIINÆ.

Test spiral, Rotaliform, rarely evolute, very rarely irregular or acervuline.

GENUS *Patellina*, WILLIAMSON.

Test conical, consisting of an external layer of spirally arranged or annular chambers divided into chamberlets; the interior of the cone filled either with hyaline shell-substance or by an aggregation of compressed chambers. *Lower Cretaceous to Recent.*

It seems advisable to restrict this genus to the hyaline forms, and to retain the generic terms *Orbitolina* and *Conulites* for the subarenaceous fossils, which are nevertheless morphologically similar to the above genus.

EXAMPLE.—*P. corrugata*, Williamson, 'Recent Foram. Gt. Britain,' 1858, p. 46, pl. iii. figs. 86–89.

It is interesting to note that this identical species, held to be a degenerate form of the subarenaceous type *Orbitolina*, was existing in the seas of the Lower Cretaceous period at the same time as the larger morphological types, as evidenced by its occurrence in the prolific fauna of the Bargate stone series in Surrey. This interesting little species is distinguished from the larger fossil forms by its clear hyaline shell-structure. Like the preceding genus, *Spirillina*, it seems most at home in fairly shallow water. *Aptian to Recent.* (Plate 12, figs. B, *b*.)

GENUS *Cymbalopora*, HAGENOW.

Test more or less trochoid or complanate. Segments of the trochoid forms spiral at the apex, subsequently arranged concentrically round a deep umbilical vestibule with which each chamber communicates by a neck. Complanate forms with a row of pores along the septal depressions of the inferior surface. Pelagic type with large inflated chamber covering the base of the shell. *Upper Cretaceous to Recent.*

EXAMPLE.—*C. Poeyi* (D'Orbigny), (*Rosalina*), 'Foram. Cuba,' 1839, p. 100, pl. iii. figs. 18–20.

This is a common species in the coral sands of low latitudes. It appears to be commonest in shallow water, but is found down to a depth of over 600 fathoms. Some of the varieties of this form are often found growing attached to seaweed. In fresh specimens the test, especially the apical portion, is stained a deep brown or purplish red, with the sarcode. *Recent.* (Plate 12, fig. C.)

PELAGIC TYPE.

C. (*Tretomphalus*) *bulloides* (D'Orbigny), 'Foram. Cuba,' 1839, p. 104, pl. iii. figs. 2–5.

The chief difference in this form is the large inflated chamber which is developed from the inferior surface of the test of an ordinary *Cymbalopora* of the variety *squamosa*.

This pelagic modification is particularly interesting on account of the frequent occurrence of embryonic shells living within the balloon-like chamber, and which are liberated through an entosolenian orifice. *Recent.* (Plate 12, fig. D.)

GENUS *Discorbina*, PARKER and JONES.

Test free or adherent, Rotaliform; plano-convex or trochoid, rarely complanate; aperture an arched slit, often protected by an umbilical flap—the flaps sometimes forming a whorl of subsidiary chambers. Shell-texture somewhat coarsely porous. *Lower Cretaceous to Recent.*

EXAMPLE.—*D. patelliformis*, Brady, 'Rep. "Chall."' vol. ix. 1884, p. 647, pl. lxxxviii. fig. 3 *a–c*; pl. lxxxix. fig. 1 *a–c*.

This neatly built species is characteristic of the genus. The lower surface of the test shows the granulated surface or exogenous shell-layer, which in some species presents the form of sutural thickenings along the radial margins of the chambers, the astral arrangement of which gave rise to the quasi-generic group the *Asterigerinæ*.

D. patelliformis has occurred in the Pacific, and from the shores of Ceylon, Madagascar, the Mauritius, Malta, and South Australia. It is chiefly confined to shallow water. *Recent.* (Plate 12, figs. E, *e*.)

GENUS *Planorbulina*, D'ORBIGNY.

Test normally adherent; compressed or complanate segments very numerous; commencing growth on a spiral plan, but subsequently becoming more or less cyclical; the lipped apertures of the individual segments opening externally at the periphery. Aberrant varieties often wild-growing and irregular, sometimes acervuline. Shell-wall coarsely porous.

The granulate discoidal forms lately described from Cebu, Philippines, by Schlumberger, under the name of *Linderina*, may belong to this type of Foraminifera. *Tertiary to Recent.*

Example.—*P. larvata*, Parker and Jones, 'Ann. and Mag. Nat. Hist.' ser. 3, vol. v. 1860, p. 294; 'Phil. Trans.' vol. clv. 1865, p. 379, pl. xix. figs. 3 *a*, *b*.

This parasitic form is usually of a regularly discoidal shape, and is characterised by the acervuline centre, with the marginal ring of apertural chambers. It is often abundant in sands of coral areas. *Recent.* (Plate 12, fig. F.)

Genus *Truncatulina*, D'Orbigny.

Test free or adherent, Rotaliform; the inferior face generally more convex than the superior. Shell-wall coarsely porous; surface sometimes tuberculated, especially in old shells. Aperture a curved slit at or near the superior margin of the inner edge of the final segment, sometimes with a phialine neck and lip. In one instance the aperture is compound, peripherical (epistomine), and normal. *Carboniferous to Recent.*

Example.—*T. lobatula*, Walker and Jacob sp. (*Nautilus*), Adams's 'Essays,' Kanmacher's ed., 1798, p. 642, pl. xiv. fig. 36.

Of the plano-convex types of *Truncatulina* this is perhaps the most characteristic form, and it is certainly the best known. It is abundant in almost every shore-sand, and is found increasing in rarity down to 3,000 fathoms.

T. lobatula is often found adherent to marine fragments, and it sometimes covers its test with a nidus of loosely agglutinated sand; possibly a tentative experiment in view of becoming an arenaceous foraminifer. *Carboniferous to Recent.* (Plate 12, figs. G, *g*.)

GENUS *Anomalina*, PARKER and JONES.

Characters similar to those of *Truncatulina*, except that the two faces are more nearly alike, the general contour being biconcave or subnautiloid, and the whorls more or less evolute. *Lower Cretaceous to Recent.*

EXAMPLE—*A. grosserugosa*, Gümbel sp. (*Truncatulina*), 'Abhandl. d. k. bayer. Akad. Wiss.' Cl. ii. vol. x. 1868, p. 660, pl. ii. figs. 104 *a*, *b*.

The present example has a stoutly built test, with fewer chambers than in some other species of this genus, and the perforations are very conspicuous. As a fossil its earliest appearance is in the Bargate beds of Surrey. It is well distributed in modern deep-sea deposits, both as to depth and locality. *Lower Cretaceous to Recent.* (Plate 12, figs. H, *h*.)

GENUS *Carpenteria*, GRAY.

Test adherent, in the smaller forms or young stage spiral; convex, monticular, cylindrical, or branching; segments more or less inflated, sometimes irregularly or sinuously disposed, in the smaller forms spreading radially or superimposed vertically; aperture at the apex of the final segment, or when compound situated in prolonged simple or arborescent tubes. Canal system, when present, rudimentary. *Cretaceous to Recent.*

The examples referred by Roemer, Goldfuss, and Reuss to the genus *Thalamopora*, and which have been well illustrated by the latter author, are without doubt referable to *Carpenteria.* They represent a cylindrical modification of the genus.

EXAMPLES.—*C. balaniformis*, Gray, 'Proc. Zool. Soc. Lond.' vol. xxvi. 1858, p. 269, figs. 1–4.

This, the smallest form of the present genus, is usually found in considerable numbers where it occurs. It is often attached to corals, the surfaces of which are sometimes dotted over quite numerously with the little barnacle-shaped tests. It is usually associated with other species of adherent Foraminifera found in common with this one, in tropical seas. *Recent.* (Plate 12, fig. I.)

C. proteiformis, Goës, 'K. Svenska Vet. Akad. Handlingar,' vol. xix. No. 4, 1882, p. 94, pl. vi. figs. 208–214, pl. vii. fig. 215–219.

The above is a few-chambered form of upright growth. As its name implies, it is very variable in shape. Fig. J is typical of the species. Goës found this form in the Caribbean Sea at 300 fathoms, and it has since been found in the lagoon of the Funafuti Atoll, Ellice Islands. *Recent.* (Plate 12, fig. J.)

GENUS *Rupertia*, WALLICH.

Test columnar, growing attached by a slightly spreading base; segments numerous, spirally arranged; aperture at the inner margin of the terminal segment. *Recent.*

EXAMPLE.—*R. stabilis*, Wallich, 'Ann. and Mag. Nat. Hist.' ser. 4, vol. xix. 1877, p. 501, pl. xx.

This species exists in great abundance in the colder area of the Faröe Channel, in 632 fathoms. It has been found in other localities, but very sparingly. *Recent.* (Plate 12, fig. K.)

GENUS *Pulvinulina*, PARKER and JONES.

Test Rotaliform, superior side usually thickest; shell with rare exceptions very finely porous; segments fewer in number than in the other ROTALIINÆ. Shell-thickening usually taking the form of external sutural limbation. Aperture typically a large slit at the base of the umbilical margin of the last segment, often irregular both as to form and position; sometimes with a second slitlike aperture at the peripheral angle of the segments, chiefly found in the group of the *P. elegans* type (*Epistomina*). Face of the terminal segment sometimes inflated and studded with larger perforations. Some species pelagic. *Carboniferous to Recent.*

EXAMPLE.—*P. Menardii*, D'Orbigny sp. (*Rotalia*), 'Ann. Sci. Nat.' vol. vii. 1826, p. 273, No. 26; 'Modèle,' No. 10.

This is an abundant species in certain pelagic deposits of the present day, where it often constitutes the larger proportion of the material. It is widely distributed in its geographical range both north and south of the equator. Its geological occurrence commences in the Chalk-marl, and it is found at many horizons in Tertiary strata. (Plate 12, figs. L, *l*, *l'*.)

GENUS *Rotalia*, LAMARCK.

Test Rotaliform, shell-wall very finely porous; with an exogenous deposit in the form either of embossed septal lines or of granulation of the sutures near the umbilicus. Aperture a neatly arched slit, nearly median. Larger species have double septa and a system of interseptal canals. *Lower Cretaceous to Recent.*

EXAMPLE.—*R. Soldanii*, D'Orbigny sp. (*Rotalina*), 'Ann. Sci. Nat.' vol. vii. 1826, p. 278, No. 5; 'Modèle,' No. 36.

The shell of this species exhibits the extreme type of the plano-convex *Rotaliæ*. *R. Soldanii* is widely distributed in our modern seas, and occurs most frequently at depths between 1,000 and 2,000 fathoms. The type-form first makes its appearance in strata of Eocene age, whilst the variety *nitida* has been recorded from beds as old as the Gault. (Plate 12, figs. M, *m.*)

GENUS *Calcarina*, D'ORBIGNY.

Test Rotaliform, lenticular; periphery furnished with radiating (sometimes branching) spines; supplemental skeleton and canal system very largely developed. *Chalk to Recent.*

Example.—*C. hispida*, Brady, 'Proc. R. Irish Acad.' ser. 2, vol. ii. 1876, p. 590; 'Rep. "Chall."' vol. ix. 1884, p. 713, pl. cviii. figs. 8, 9.

This pretty little aculeate form is very common in tropical parts of the Pacific and Indian Oceans, in the neighbourhood of coral islands. It usually affects shallow water down to 60 fathoms; at Funafuti it occurs sparingly at 200 fathoms. *Recent.* (Plate 12, fig. N.)

Sub-family 3. Tinoporinæ.

Test consisting of irregularly heaped chambers with or without a more or less distinctly spiral primordial portion; for the most part without any general aperture.

Genus *Tinoporus*, Montfort.

Test lenticular or subspheroidal, with radiating marginal spines and tuberculated surface; central chambers forming a plano-spiral disc, which is thickened by an aggregation of smaller chambers arranged in tiers on the two sides. No general aperture, the extrusion of sarcode taking place chiefly through the canals of the spurlike growths of the supplemental skeleton. *Recent.*

On account of the somewhat dubious depiction of Montfort's type this genus is referred to as *Baculogypsina* by many authors.

Example.—*T. baculatus*, Montfort, 'Conchyl. System.' vol. i. 1808, p. 146, 37^e^ genre; Carpenter, 'Phil. Trans.' 1860, p. 557, pls. xviii. xxi.

The present species is often associated with *Calcarina* in the littoral sands of coral islands. It is easily distinguished from its congener by the surface tuberculations, the ends of the pillars of exogenous shell-growth, among other characters. *T. baculatus* is found in extraordinary abundance in some of the sands of the Pacific, the orange-brown tests giving the deposits quite a colouring of their own. It is most characteristic of the shore-sands of the reef, but has been obtained from a depth of 200 fathoms, although sparingly. *Recent.* (Plate 12, fig. O.)

GENUS *Gypsina*, CARTER.

Test free or attached, spheroidal or spreading; structure acervuline, radiating, or laminated; primordial chambers spiral. The chambers are rounded or polyhedral; coarsely perforated. There is no supplemental skeleton, nor canal system. Apertures obscure, sometimes marginal.

This genus also includes the type to which Carter gave the name *Aphrosina*, and which appears to be a plano-convex modification of *Gypsina inhærens*, Schultze sp. *Cretaceous to Recent.*

EXAMPLE.—*G. vesicularis*, Parker and Jones sp. (*Orbitolina*), 'Ann. and Mag. Nat. Hist.' ser. 3, vol. vi. 1860, p. 31, No. 5.

This subconical form is a good type of the genus. The surface is marked with fine raised lines, the boundaries of the polyhedral chambers. *G. vesicularis* and its attendant varieties occur in the sands of

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"Chall."

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crowded with sponge spicules, especially at the apices of the test. No canal system. *Tertiary to Recent.*

EXAMPLE.—*P. miniaceum*, Pallas sp. (*Millepora*), 'Elenchus Zoophytorum,' 1766, p. 251; Brady, 'Rep. "Chall."' vol. ix. 1884, p. 721, pl. c. figs. 5–9; pl. ci. fig. 1.

This is the small coral-like organism which has been frequently referred by earlier authors to the Zoophytes. Its branching dendroid test is usually found attached to shells of molluscs, corals, and other objects. The pink colouring matter is present in specimens from fairly deep water, and is as vivid in those from 150 fathoms as in those near the surface.

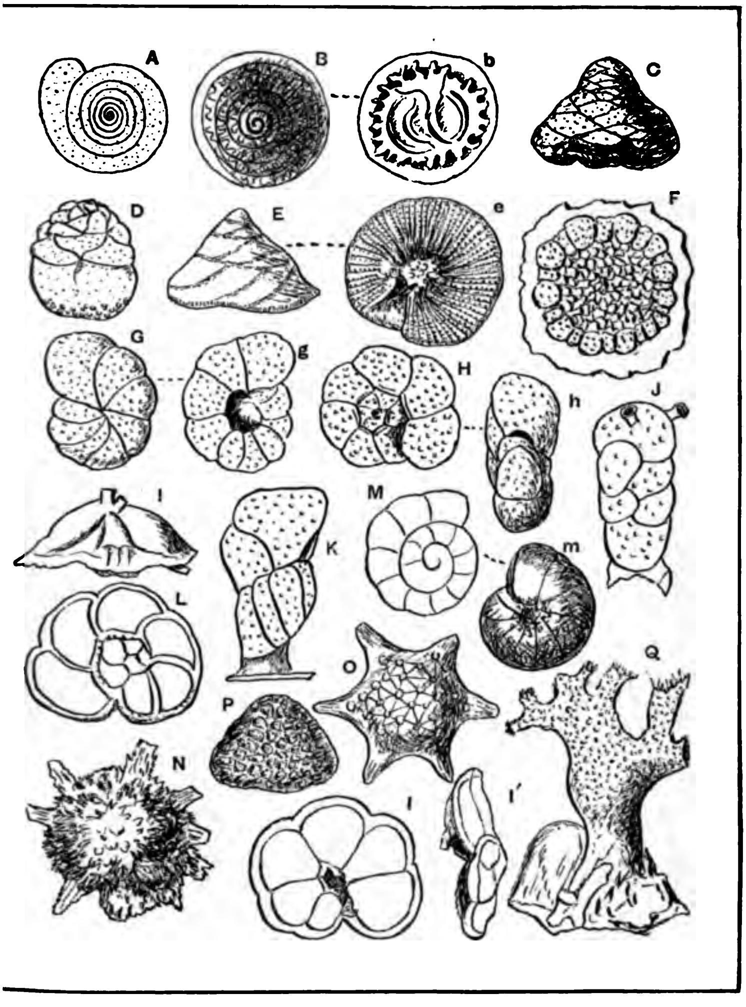
The encrusting species of this genus is usually snow-white in appearance.

P. miniaceum is common in tropical and subtropical seas, and its home is in the shallower waters of those areas. *Recent.* (Plate 12, fig. Q.)

EXPLANATION OF PLATE 12.

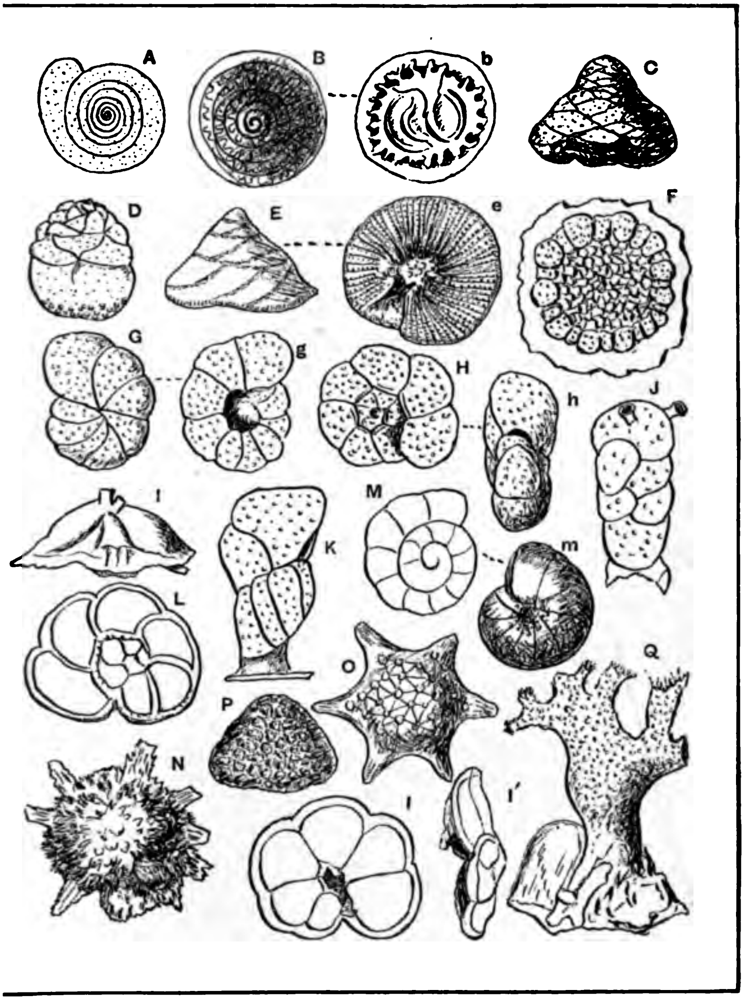
Fig.	
A.	*Spirillina vivipara*, Ehrenberg (after Brady). × 65.
B, *b*.	*Patellina corrugata*, Williamson : B, superior, *b*, inferior, surface. × 75.
C.	*Cymbalopora Poeyi*, D'Orbigny sp. (after Brady). × 25.
D.	*C.* (*Tretomphalus*) *bulloides*, D'Orbigny (after Brady). × 30.
E, *e*.	*Discorbina patelliformis*, Brady ; E, lateral aspect ; *e* inferior aspect. × 50.
F.	*Planorbulina larvata*, Parker and Jones (after Brady). × 17.
G, *g*.	*Truncatulina lobatula*, Walker and Jacob, sp. (after Goës): G, superior aspect ; *g*, inferior aspect. × 16.
H, *h*.	*Anomalina grosserugosa*, Gümbel (after Brady) ; H, superior aspect ; *h*, peripheral aspect. × 20.
I.	*Carpenteria balaniformis*, Gray (after Chapman). × 4.
J.	*C. proteiformis*, Goës. × 8.
K.	*Rupertia stabilis*, Wallich (after Goës). × 21.
L, *l*, *l′*.	*Pulvinulina Menardii*, D'Orbigny sp. (after Brady): L, superior ; *l*, inferior ; *l′*, peripheral, aspect. × 15.
M, *m*.	*Rotalia Soldanii*, D'Orbigny sp. ; M, superior, *m*, inferior, aspect. × 18.
N.	*Calcarina hispida*, Brady. × 15.
O.	*Tinoporus baculatus*, Montf. (after Brady). × 10.
P.	*Gypsina vesicularis*, Parker and Jones sp. (after Brady). × 10.
Q.	*Polytrema miniaceum*, Pallas sp. × 8.

PLATE 12.



Family IX. ROTALIIDÆ.

PLATE 12.



Family IX. ROTALIIDÆ.

phistegina has a more advanced type of shell nearer the true nummulites; in fact, it is difficult at times to be certain whether one is dealing with these forms or Nummulites when its chief character, the asymmetry of the test, is more or less obscure. Until lately it was held by Rhizopodists that *Amphistegina* had no interseptal canal system, but its presence has now been proved both in the fossil and recent examples.

Operculina is typically evolute and outspread, but the earlier chambers are embracing. *Heterostegina* is comparable with the last-named type, but the chambers are partitioned off into chamberlets.

The discoidal test of *Nummulites* consists of numerous chambers wound in a flat spiral, with the walls of the chambers double. The intermediate space is traversed by interseptal canals, which open out on the surface of the test. The walls of the chambers of each coil are so extended by alar prolongations or flaps that they become equitant and completely cover up the preceding whorl of the shell, and the test shows no signs of septation externally. The sinuous lines seen on the surface of *Nummulites* are the junctions of the alar extensions of the outer septal walls of the chambers.

The genera *Cycloclypeus* and *Orbitoides*, which constitute the sub-family CYCLOCLYPEINÆ, are examples of a cyclical method of growth in these shells. In the former genus there is a single layer of annular chambers divided into chamberlets, and with superimposed supplementary skeleton and numerous exo-

To turn to the separate divisions of this family, the sub-family FUSULININÆ has the important genus *Fusulina* for its type. This, with the various allied genera and sub-genera, are fossil forms, and restricted to palæozoic strata. Their shell-structure is not typically nummuline, for the canal system and supplementary skeleton appear to be absent.

The next group of the POLYSTOMELLINÆ is a farther step towards the higher shell-structure seen in the Nummulites. In *Nonionina* the shell-wall is still simple in character, but the suture lines are sometimes thickened by an extra shell-layer. *Polystomella* comprises an instructive series of shells in which the graduations may be traced from those with a simple series of interseptal canals opening out at the suture lines by a row of pores, to those with a more complicated system, and with a varying amount of exogenous shell-structure forming a true supplemental skeleton, as well as secondary thickening of the test in the form of septal bridges laid at intervals across the sutural furrows, and also sutural costæ.

The genus *Archædiscus* represents the simplest form of the typical nummulite group, in being little more than a simple non-septate or partially septate tube wound round an axis which at intervals changes its direction, as in many of the milioline genera. This genus, which is restricted to Carboniferous rocks, shows an affinity with the nummuline forms in having a thick laminated shell. It is finely porous, but also exhibits a secondary kind of tubulation in the form of numerous coarser pores or canals. *Am-*

phistegina has a more advanced type of shell nearer the true nummulites; in fact, it is difficult at times to be certain whether one is dealing with these forms or Nummulites when its chief character, the asymmetry of the test, is more or less obscure. Until lately it was held by Rhizopodists that *Amphistegina* had no interseptal canal system, but its presence has now been proved both in the fossil and recent examples.

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Sub-family 1. FUSULININÆ.

Test bilaterally symmetrical; chambers extending from pole to pole; each convolution completely enclosing the previous whorls. Shell-wall finely tubulated. Septa single, or rarely double; no true interseptal canals. Aperture a single elongated slit, or row of small rounded pores, at the inner edge of the final segment.

GENUS *Fusulina*, FISCHER.

Test fusiform or subglobular; chambers entire, or only subdivided by the infolding of the septal wall; aperture an elongated central fissure. *Carboniferous and Permian.*

EXAMPLE. — *F. cylindrica*, Fischer. 'Oryctogr. Gouv. Moscou,' 1830–37, p. 126, pl. xiii. figs. 1–5.

The test of this important rock-forming species is spindle-shaped and rounded at the ends. The shell is marked with longitudinal furrows, and the slitlike aperture is situated in the centre of the overlapping angle of the septal plane. *Carboniferous and Permian.*

Some species of *Fusulina* attain a length of half an inch. They constitute a large proportion of the Upper Carboniferous limestones of certain localities, as in Russia, the Arctic Regions, Armenia, India, China, Japan, the United States (Iowa, Illinois, Kansas, Utah, New Mexico, and California), and British Columbia. In Central Europe also the Zechstein (of Permian age) contains *Fusulina*. (Plate 13, figs. A, *a*.)

The sub-genera *Hemifusulina* and *Fusulinella* of Möller are modifications of the typical *Fusulina*, and they are confined to the Carboniferous formation. *Hemifusulina* resembles *Fusulina* in form and general structure, but with the exception that it possesses a double septal wall. *Fusulinella* may be compared with a *Fusulina* which has been compressed on the axis of the umbilicus, the resulting form being a complanate nautiloid shell, like *Nonionina*. The brown bituminous Carboniferous limestone of Russia and China contains *Fusulina*, *Fusulinella*, and *Schwagerina*. The specimens of the latter genus are often found infilled with the hydrocarbonaceous material of the rock-matrix.

GENUS *Schwagerina*, MÖLLER.

Test subglobular, elongated, or subcylindrical, seldom fusiform; chambers subdivided by true secondary septa; aperture either a simple central fissure or a row of rounded pores. *Carboniferous*.

EXAMPLE.—*S. princeps*, Ehrenberg sp. (*Borelis*), 'Mikrogeologie,' 1854, pl. xxxvii. figs. x. c, 1–4;

Brady, 'Geol. Mag.' 1875, p. 537, pl. xiii. figs. 6 *a*, *c*.

The above species gives one a good idea of the chief characters of the genus, and by referring to the drawing (fig. *b* of Plate 13) the perfect septation will be noticed, which forms its distinctive feature. It occurs as a fossil in the Carboniferous limestone of Russia, China, and Sumatra. (Plate 13, figs. B, *b*.)

Sub-family 2. POLYSTOMELLINÆ.

Test bilaterally symmetrical; nautiloid. Lower forms without supplemental skeleton or interseptal canals; higher types with canals opening at regular intervals along the external septal depressions.

GENUS *Nonionina*, D'ORBIGNY.

Supplemental skeleton either absent or rudimentary, and confined to the umbilical region; no external septal pores or bridges. Aperture a simple curved slit. *L. Cretaceous to Recent.*

EXAMPLE.—*N. umbilicatula*, Montagu sp. (*Nautilus*), 'Test. Brit.' 1803, p. 191; Suppl. p. 78, pl. xviii. fig. 1.

The evenly rounded nautiloid contour of the genus is well shown in the present form; it is chiefly distinguished from the other species of the genus by its conspicuously sunken umbilical area.

As a recent species *N. umbilicatula* is widely distributed. The fossil specimens date from the Middle Eocene. (Plate 13, figs. C, *c*.)

GENUS *Polystomella*, LAMARCK.

Supplemental skeleton, septal bridges, and canal system more or less fully developed; canals opening externally at the umbilicus, and by a single or double row of pores along the sutures. Aperture a V-shaped line of perforations at the base of the septal face. *Middle Jurassic to Recent.*

EXAMPLE.—*P. macella*, Fichtel and Moll sp. (*Nautilus*), 'Test. Microgr.' 1798, p. 66, pl. x. figs. *e–g*.

The chief features of this species are its compressed form and acute periphery. The points round the shell margin are often produced to a considerable extent. *P. macella* appears to be a modification of the more inflated type *P. crispa*.

It is commonest in shallow water, and is found in all parts of the world excepting the extreme northern and southern portions. *Jurassic to Recent.* (Plate 13, fig. D.)

The sub-genus *Faujasina*, D'Orbigny, includes certain forms which, although exhibiting the general characters of *Polystomella*, are plano-convex in shape, the entire spiral portion being visible only on the flat face, and the last whorl on the convex side. It is isomorphous with *Truncatulina lobatula*.

The type form *F. carinata* (D'Orbigny, 'Foram. Foss. Vienne,' 1846, p. 194, pl. xxi. figs. 29–31) was first obtained from the Chalk of Maestricht. It also occurs in various Tertiary deposits. (Plate 13, figs. E, *e*.) *Upper Chalk to Pliocene.*

Sub-family 3. NUMMULITINÆ.

Test lenticular or complanate; lower forms with thickened and finely tubulated shell-wall, but no intermediate skeleton; higher forms with supplemental skeleton and complex canal system.

GENUS *Archædiscus*, BRADY.

Test lenticular, consisting of a non-septate tube coiled upon itself in constantly varying direction, embedded in a thick mass of finely tubulated shell-substance. No supplemental skeleton nor canal system. *Carboniferous.*

EXAMPLE.—*A. Karreri*, Brady, 'Ann. Mag. Nat. Hist.' ser. 4, vol. xii. 1873, p. 286, pl. xi.; 'Monogr. Carb. and Perm. Foram.' (Pal. Soc.), 1876, p. 142, pl. xi. figs. 1–6.

The only species of this remarkable genus is of a lenticular rounded form, with a somewhat angular margin. The aperture is situated at the open end of the tubular cavity, in various positions on the periphery, according to the development of the shell; rounded or crescentic, and simple. The presence of the coarser pores in this shell probably points to the early stage of a canal system, which is, however, obscured by the mineralisation of the fossils. It appears to be restricted to the Carboniferous formations of the British Islands. (Plate 13, figs. F, *f*.)

GENUS *Amphistegina*, D'ORBIGNY.

Test spiral, lenticular, inequilateral; chambers equitant, the alar prolongations on one side simple, on the other divided by deep constrictions, so as to form supplementary lobes. Shell-wall thickened near the umbilicus, finely perforated; the exogenous thickening non-tubulous, and in transverse section appearing as two cones of different sizes with the apices opposed. A finely ramifying canal system present both in the septa and in the shell-wall. *Carboniferous and Tertiary to Recent.*

EXAMPLE.—*A. Lessonii*, D'Orbigny, 'Ann. Sci. Nat.' vol. vii. 1826, p. 304, No. 3, pl. xvii. figs. 1-4.

This is a very variable form, and the names under which it has been described are nearly as numerous as its variations. *A. Lessonii* has a test which ranges in form from a thin complanate disc to a subspherical or dome-shaped test. Even in one dredging many gradations in form may be found.

It is usually found in the tropical areas of the Atlantic, Pacific, and Indian Oceans; and is commonest in water of less depth than 30 fathoms, but also occurs at greater depths, even down to 1,750 fathoms. *Middle Eocene to Recent.* (Plate 13, figs. G, *g*, *g'*.)

GENUS *Operculina*, D'ORBIGNY.

Shell typically complanate and plano-spiral, with the whole of the convolutions visible; the earlier whorls more or less embracing. Interseptal and

EXPLANATION OF PLATE 18.

FIG.

A, *a*. *Fusulina cylindrica*, Fischer: A, external and internal aspect, × 6; *a*, transverse section, × 15.

B, *b*. *Schwagerina princeps*, Ehrenberg sp. (after Brady): A, external view. × 1½; *b*, transverse section of test, × 8.

C, *c*. *Nonionina umbilicatula*, Montagu sp. (after Parker and Jones): C, lateral aspect; *c*, oral aspect. × 30.

D. *Polystomella macella*, Fichtel and Moll sp. (after Brady). × 60.

E, *e*. *Faujasina carinata*, D'Orbigny: E, inferior aspect (convex surface); *e*, peripheral aspect.

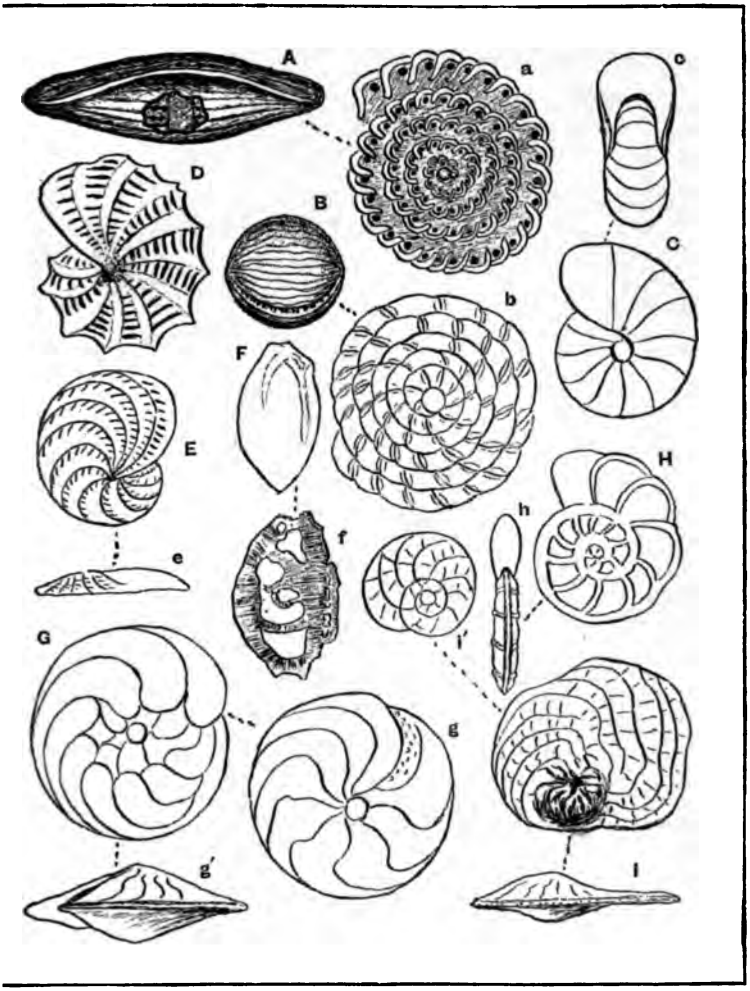
F, *f*. *Archædiscus Karreri*, Brady: F, periphero-lateral aspect; *f*, transverse section of test. × 20.

G, *g*, *g'*. *Amphistegina Lessonii*, D'Orbigny: G, inferior lateral aspect, showing the astral lobes; *g*, superior lateral aspect, with granulations near oral region, *g'*, peripheral aspect. (After Parker, Jones, and Brady.) × 55.

H, *h*. *Operculina ammonoides*, Gronovius sp.: H, lateral aspect; *h*, peripheral aspect. × 50.

I, *i*, *i'*. *Heterostegina depressa*, D'Orbigny: I, lateral aspect of a full-grown shell; *i*, peripheral aspect, × 7; *i'*, young shell, × 25.

PLATE 13.



Family X. NUMMULINIDÆ.

marginal canals conspicuously developed. *Lower Cretaceous to Recent.*

EXAMPLE.—*O. ammonoides*, Gronovius sp. (Nautilus), 'Zooph. Gron.' 1781, p. 282, No. 1220, and p. v.

A small complanate form with comparatively few chambers and with limbate or thickened sutures. It is found at the present day in fairly shallow water. *Pliocene to Recent.* (Plate 13, figs. H, *h.*)

GENUS *Heterostegina*, D'ORBIGNY.

Test resembling *Operculina* in general contour; chambers long and narrow, and divided into chamberlets; aperture a row of pores on the outer septal face. *Eocene to Recent.*

EXAMPLE.—*H. depressa*, D'Orbigny, 'Ann. Sci. Nat.' vol. vii. 1826, p. 305, pl. xvii. figs. 5–7; 'Modèle,' No. 99.

The present species is the type of the genus, and the many variations which have been described as species differ in little from this form. The shell presents itself in the two stages having the large or small initial chamber, in common with many other types of Foraminifera, and, as is often the case, the small-chambered form is much rarer than the large-chambered form. In the dredgings from Funafuti, where these two conditions were observed, the writer found them in the proportion of about 500 of Form A (the megalospheric shell) to 1 of Form B (the microspheric shell). It inhabits moderately shallow water often in the neighbourhood of coral reefs. *Eocene to Recent.* (Plate 13, figs. I, *i*, *i'*.)

GENUS *Nummulites*, LAMARCK.

Test lenticular or complanate, plano-spiral, regular. Segments equitant, the alar prolongations of each convolution completely enclosing the previou whorls. Aperture simple, close to the periphery o the previous convolution. Supplemental skeleto provided with a complex canal system. *Carbonife rous*, (?) *Jurassic, Tertiary, and Recent.*

The palæozoic specimens of this genus are smal but characteristic; they were found in the Carboniferous limestone of Belgium. *Nummulites* is, however, peculiarly a Tertiary form, and was abundant in Eocene and Oligocene times, especially in the former. The recent specimens are not far removed in structure from *Operculina* and *Amphistegina*.

EXAMPLE.—*N. elegans*, Sowerby sp. (*Nummularia*), 'Mineral Conchology,' vol. vi. 1826, p. 76, pl. xxxviii. fig. 2; Rupert Jones, 'Quart. Journ. Geol. Soc.' vol. xliii. 1887, p. 132, pl. xi. figs. 1–9.

This species, with its thin complanate test, is found in abundance in certain horizons of the Barton Beds of the Isle of Wight and Hampshire. (Plate 14, figs. A, *a*, B.)

GENUS *Assilina*, D'ORBIGNY.

Test complanate, structure similar to that of *Nummulites*, but the alar extensions of the chamber-walls thin and closely superimposed, so that the outline of the convolutions is visible externally. *Eocene.*

EXAMPLE.—*A. exponens*, Sowerby sp. (*Nummularia*), 'Trans. Geol. Soc. Lond.' ser. 2, vol. v. 1834 (1840), p. 719, pl. lxi. figs. 14 *a–e*. D'Archiac and Haime, 'Descr. Anim. foss. groupe Nummulitique de l'Inde,' vol. i. 1853, p. 148, pl. x. figs. 1–10.

The shell of this species is discoidal and thin, with a central depression more or less pronounced. The surface of the test is covered, especially in the central area, with fine radiating pustular or granular lines. The septation of the shell is more clearly seen towards the periphery. It is a wide-spread form, and has been found in various Eocene deposits in Spain, France, Switzerland, Bavaria, Carinthia, the Carpathians, Northern Africa, Asia Minor, and in the Cashmere Mountains, upon the right bank of the River Indus, and in the Province of Cutch, in India. (Plate 14, figs. C, *c*.)

Sub-family 4. CYCLOCLYPEINÆ.

Test complanate with a thickened centre, or lenticular; consisting of a disc of chambers arranged in concentric annuli, with a more or less lateral thickening of laminated shell-substance, or of acervuline layers of chamberlets. Septa double, and furnished with a system of interseptal canals.

GENUS *Cycloclypeus*, CARPENTER.

Discoidal layer usually single; with superimposed laminæ of finely tubulated shell-substance, thickest at the centre, often only slightly developed (especially in the microspheric form). *Eocene to Recent.*

EXAMPLE.—*C. Carpenteri,* Brady, 'Rep. "Chall."' vol. ix. 1884, p. 752; also *ibid.* p. 751, pl. cxi. figs. 8 *a, b* (*C. Guembelianus*).

A great deal of interest attaches to the above species, not only on account of its large dimensions as a foraminifer, but also because of its conspicuous occurrence in the two stages of shell development, forms A and B. The megalospheric form is often found in the sands of the coral islands, and bore the name of *C. Guembelianus.* The other form, the microspheric, occurs quite locally in just a few places, and is the original type on which Carpenter's lucid descriptions of the genus were based (see 'Phil. Trans.' vol. cxlvi. 1856, p. 155, pl. xxx. figs. 1 and 3, and 'Introd. Study Foram.' 1862, p. 292, pl. xix. fig. 2).

The places whence *C. Carpenteri* have been obtained are Borneo, the Macclesfield Bank, in the China Sea, Solomon Islands, the Mauritius, and the following places in the Pacific: Tonga, Fiji, Tongatabu, and Funafuti. At the latter place *Cycloclypeus* occurs in great abundance at certain depths, at about 50 to 60 fathoms, and the limit of its range there seems to be from 30 to 200 fathoms. *Recent.* (Plate 14, figs. D, *d*, E.)

GENUS *Orbitoides*, D'ORBIGNY.

Median plane composed of chamberlets arranged in regular annuli round a distinct central chamber or chambers; thickened on either side by layers of flattened chamberlets, more or less irregularly disposed. *Upper Cretaceous to Miocene.*

EXAMPLE.—*O.* (*Discocyclina*) *papyracea*, Boubée sp., Gümbel, 'Abhandl. m.-ph. Cl. k. bayer. Ak. Wiss.' vol. x. 1868 (1870), p. 690, pl. iii. figs. 3–12, 19–29.

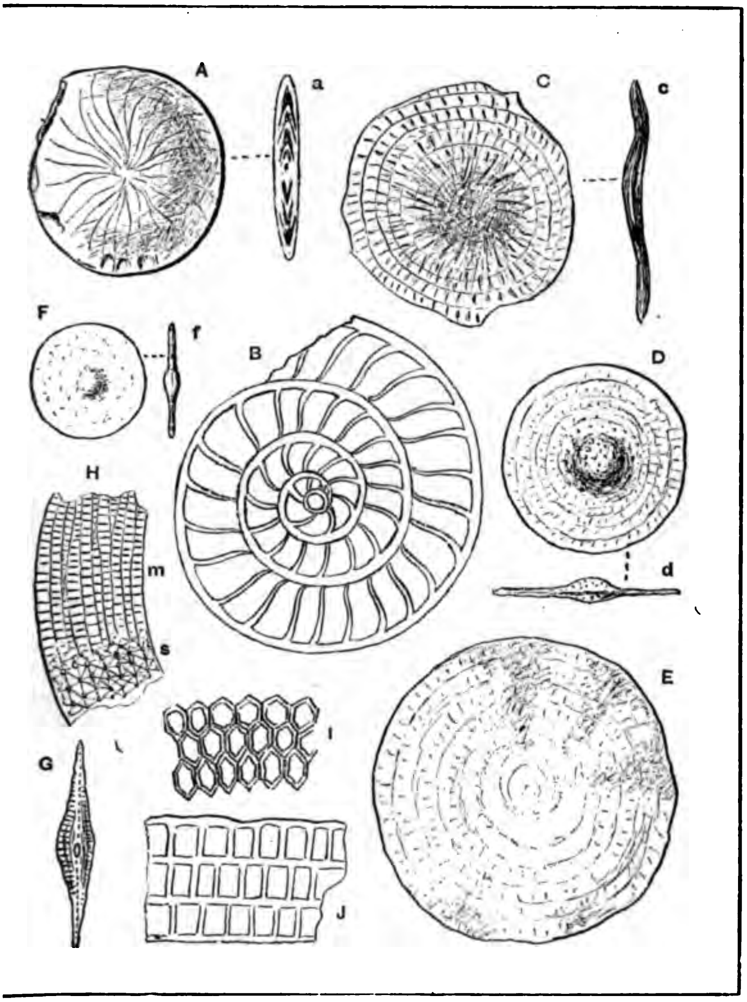
As a component of certain Tertiary limestones this species is often of very great importance. It was undoubtedly a foraminifer living in shallower water than the related type *Cycloclypeus*, which has a thinner test; and it formed extensive shell-banks, which eventually became consolidated into beds of Orbitoidal limestone. This species is easily recognised by its thickened central disc and expansive peripheral flange. *Eocene* of Europe, Egypt, Persia, and India. (Plate 14, figs. F, *f*, G, H, I.)

The chief sub-generic types of *Orbitoides* are based on the appearance of the chamberlets of the median layer. The sub-genus *Discocyclina* has the chamberlets of a rectangular form, whilst the sub-genus *Lepidocyclina* (see Plate 14, fig. I) has them of lozenge-shaped or spathulate form. The Discocyclines are apparently restricted to *Eocene* beds, and the Lepidocyclines occur in the *Upper Cretaceous*, the *Oligocene*, and the *Miocene*. Other sub-generic types are of little importance, such as *Aktinocyclina*, *Rhipidocyclina*, and *Asterocyclina*, their distinction being based on external form alone.

EXPLANATION OF PLATE 14.

FIG.	
A, *a*.	*Nummulites elegans*, Sowerby sp.: A, lateral aspect; *a*, vertical section. × 10.
B.	*N. elegans*, Sowerby sp.: median section. × 20.
C, *c*.	*Assilina exponens*, Sowerby sp.: C, lateral aspect; *c*, peripheral aspect. Natural size.
D, *d*.	*Cycloclypeus Carpenteri*, Brady: form A; D, lateral aspect; *d*, peripheral aspect. × 5.
E.	*C. Carpenteri*; form B. Natural size.
F, *f*.	*Orbitoides papyracea*, Boubée sp.: *f*, peripheral aspect. Natural size.
G.	*O. papyracea*, Boubée sp.: vertical section of a larger specimen. Natural size.
H.	*O. papyracea*, Boubée sp.: median to tangential section; *m*, rectangular chamberlets of median layer; *s*, areolated chamberlets of superficial layer. × 6.
I.	Type of *Lepidocycline* structure in median layer of *Orbitoides* (*Lepidocyclina*) *Verbeeki*, Newton and Holland. × 75.
J.	Type of Discocyline structure in median layer of *Orbitoides* (*Discocyclina*) *papyracea*, Boubée sp. × 50.

PLATE 14.



Family X. NUMMULINIDÆ (*concluded*).

CHAPTER XVII

IE GEOLOGICAL RANGE OF THE FORAMINIFERA

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EXPLANATION OF PLATE 14.

Fig.

A, *a*. *Nummulites elegans*, Sowerby sp.: A, lateral aspect; *a*, vertical section. × 10.

B. *N. elegans*, Sowerby sp.: median section. × 20.

C, *c*. *Assilina exponens*, Sowerby sp.: C, lateral aspect; *c*, peripheral aspect. Natural size.

D, *d*. *Cycloclypeus Carpenteri*, Brady: form A; D, lateral aspect; *d*, peripheral aspect. × 5.

E. *C. Carpenteri*; form B. Natural size.

F, *f*. *Orbitoides papyracea*, Boubée sp.: *f*, peripheral aspect. Natural size.

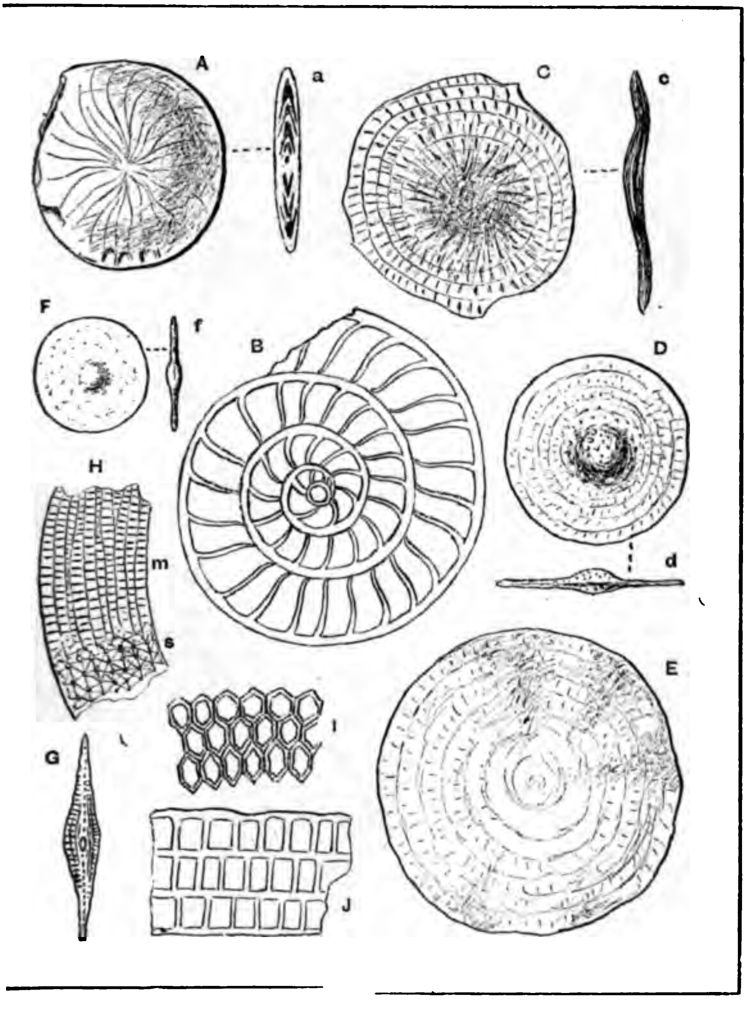
G. *O. papyracea*, Boubée sp.: vertical section of a larger specimen. Natural size.

H. *O. papyracea*, Boubée sp.: median to tangential section; *m*, rectangular chamberlets of median layer; *s*, areolated chamberlets of superficial layer. × 6.

I. Type of *Lepidocycline* structure in median layer of *Orbitoides* (*Lepidocyclina*) *Verbecki*, Newton and Holland. × 75.

J. Type of Discocyline structure in median layer of *Orbitoides* (*Discocyclina*) *papyracea*, Boubée sp. × 50.

PLATE 14.



FAMILY X. NUMMULINIDÆ (*concluded*).

CHAPTER XVII

THE GEOLOGICAL RANGE OF THE FORAMINIFERA

In commencing a survey of the various foraminiferal faunas of past ages we might naturally expect to find the remains of such lowly organised and adaptable creatures as Foraminifera in great abundance in the oldest fossiliferous rocks. But this does not appear to be so, for the older Palæozoic series has up to the present yielded very few genera and species of this type of animal life. At one or two horizons only are their remains found in tolerable abundance, and these are generally in the form of glauconite casts. On the other hand in these oldest rocks certain examples have been found which have the hyaline type of shell, and in which the original structure has been wonderfully preserved. The majority of the older Palæozoic Foraminifera have been assigned to genera of the perforate type, such as *Lagena*, *Nodosaria*, *Globigerina*, and *Spirillina*, whilst in strata of later age in the same era the arenaceous genera *Hyperammina*, *Stacheia*, and *Textularia* make their appearance.

Seeing that the shells of the Foraminifera which are as a rule so well preserved, especially in calcareous strata, as the limestones and calcareous shales, are comparatively rare in the older rocks, we may reasonably infer that the types of Protozoa, which very probably existed in earliest times and in prodigious abundance, were chiefly represented by those forms which did not possess an investment of hard material, but consisted merely of sarcode, or perhaps were covered by a thin chitinous investment. This conjecture, however, will require proof which *prima facie* will be next to impossible to obtain, for the chitinous forms are practically unknown as fossils.

It appears by recent researches to be pretty conclusively proved that the whilom sensational *Eozoön Canadense* of the Laurentian limestone rocks of Canada and elsewhere is not a gigantic foraminifer. Whether it be a purely mineral structure or a mineralised organism of a larger type of growth, such as a hydrozoan, remains to be seen; it will not be necessary to dwell further upon it here.

Some exceedingly minute bodies resembling Foraminifera in their general form have been described by Cayeux from the Pre-Cambrian of Brittany, where they occur in quartzites and pthanites. They are, however, of such small dimensions, the largest of their segments having a diameter of only $\frac{1}{2500}$ inch, that their relation to Foraminifera may be considered somewhat doubtful.

Four noteworthy occurrences of Foraminifera have been recorded from Cambrian strata. Ehrenberg, in 1858, figured various glauconitic casts of Foraminifera from the so-called 'Silurian clay' near St. Petersburg, which apparently belong to ge dimensions; there are, however, many others the Carboniferous series which, although smaller size, are often very numerous, and therefore ortant as rock-builders. Many of these species, even genera, are more or less restricted to Carboniferous system. Among other Carboni- us types we may mention the genera *Haplophrag- m*, *Stacheia*, *Nodosinella*, *Endothyra* (generally a

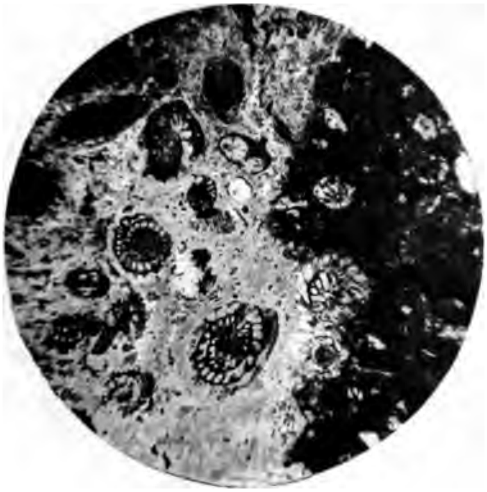


Fig. 29.—Fusulina Limestone; Russian Carboniferous. × 6½. *Original.*

rboniferous genus, but also found in the Trias), *mmodiscus*, *Textularia*, *Valvulina*, *Lagena*, *Archæ- cus* (restricted), and *Fusulina* (restricted to Car- iferous and Permian).

The genera *Saccammina* (fig. 28) and *Fusulina* . 29) often form the larger proportion of extensive s of limestone, as we have already seen, but asionally some of the smaller types, as *Endothyra* many of the specimens. The commonest genus in point of numbers in this rock is *Spirillina* (see fig. 27), and the particular form is not so very different from a species now often met with in shallow water off the British coasts. The other genera accompanying the *Spirillinæ* of the Upper Cambrian are *Lagena*, *Nodosaria*, *Marginulina*, and *Cristellaria*.

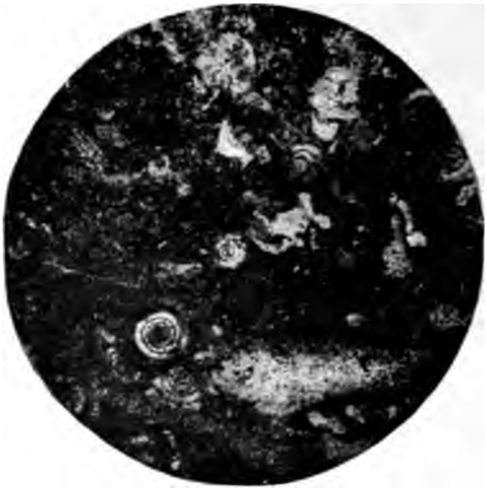


FIG. 27.—SPIRILLINA ROCK; UPPER CAMBRIAN, MALVERNS. × 36.

In the Ordovician system the shales above the Bala limestone at Guildfield, near Welshpool, have been recorded as foraminiferal by W. Keeping.

In the Silurian system the Llandovery beds of Cwm Symlog have yielded to J. F. Blake *Dentalina communis* and to W. Keeping *Textularia*, *Dentalina*, and (?) *Rotalia*.

From the Woolhope Limestone of the Malverns H. B. Brady obtained four species of *Lagena*, which referred to more recent types, although the general rface of the tests, as well as the ornamentation, is uch coarser.

In sections of the Wenlock Limestone of the idlands the writer has frequently noticed small rms of *Lagenæ*, and he has lately described some ecies belonging to the genera *Hyperammina* and *acheia* from the Wenlock Series of Gotland. The ter genus has also been obtained by Vine from the enlock shales of England, and described by him der the name of *Psammosiphon*.

The Upper Silurian of Waldron (Indiana) has lded Terquem four species of *Placopsilina*, which re found attached to crinoid stems.

The same author also found casts of Foramini- a, which he referred to *Lagenulina*, *Cristellaria*, *bulina*, *Globigerina*, and *Fusulina*, in Devonian ks at Paffrath, in the Eifel. This appears to be e only record of Foraminifera occurring in vonian strata in any country. The absence of ese organisms is very remarkable, for the condi- ns under which the deposits of Devonian age with e marine facies were laid down seem to be espe- lly favourable for the existence of Foraminifera. e usual concomitants of foraminiferal deposits e greatly in evidence in Devonian rocks, such as rals, ostracoda, and oolitic-granules, but neverthe- ss the Foraminifera are strangely wanting.

This singular paucity of Foraminifera in the evonian strata is strongly emphasised by the appa- ntly sudden appearance of a large number of genera and species in the Carboniferous system. At this period the Foraminifera were so abundant in certain areas that they often formed very extensive deposits. For example, *Saccammina* constitutes a large proportion of the rock known as the *Saccammina* limestone of England, Scotland, Ireland, and Belgium; and this genus is found throughout the Carboniferous series, but chiefly near its base. *Fusulina* is another important genus, forming the main bulk of the *Fusulina* limestones so extensively developed in the Upper Carboniferous of Russia, China, Japan, and North America; and which also occurs in Spain (Cantabrian Chain) and the Southern Alps (Upper Carniola and Carinthia), the Caucasus, Isle of Chios, Borneo, and Sumatra.

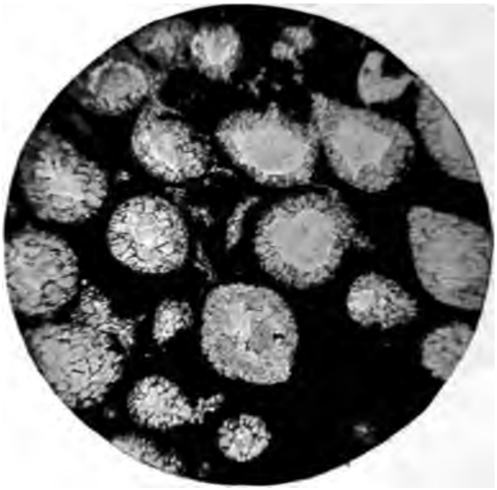


Fig. 28.—Saccammina Limestone; Carboniferous, Northumberland. ×6½. *Original.*

The two above-mentioned genera are of fairly large dimensions; there are, however, many others in the Carboniferous series which, although smaller in size, are often very numerous, and therefore important as rock-builders. Many of these species, and even genera, are more or less restricted to the Carboniferous system. Among other Carboniferous types we may mention the genera *Haplophragmium*, *Stacheia*, *Nodosinella*, *Endothyra* (generally a Carboniferous genus, but also found in the Trias), *Ammodiscus*, *Textularia*, *Valvulina*, *Lagena*, *Archædiscus* (restricted), and *Fusulina* (restricted to Carboniferous and Permian).

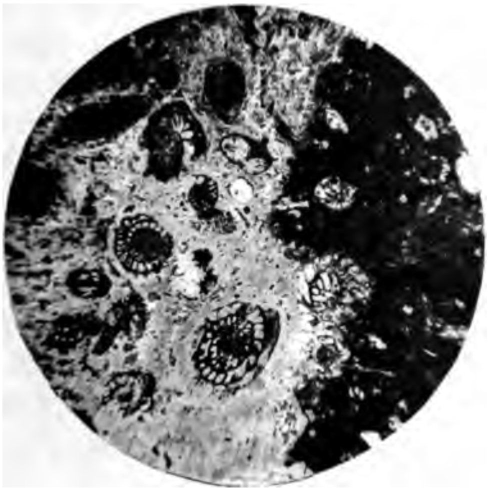


FIG. 29.—FUSULINA LIMESTONE; RUSSIAN CARBONIFEROUS. × 6½. *Original.*

The genera *Saccammina* (fig. 28) and *Fusulina* (fig. 29) often form the larger proportion of extensive beds of limestone, as we have already seen, but occasionally some of the smaller types, as *Endothyra* and *Archaediscus*, are also abundant in certain limestones, so much so, in fact, as to merit in the former case the name *Endothyra* Limestone (fig. 30). Frequently the Foraminifera are associated with other organisms, such as Ostracoda, Polyzoa, Corals, and so forth, which form together an organically derived limestone. Two other genera were recorded by Brady from the Carboniferous System which are

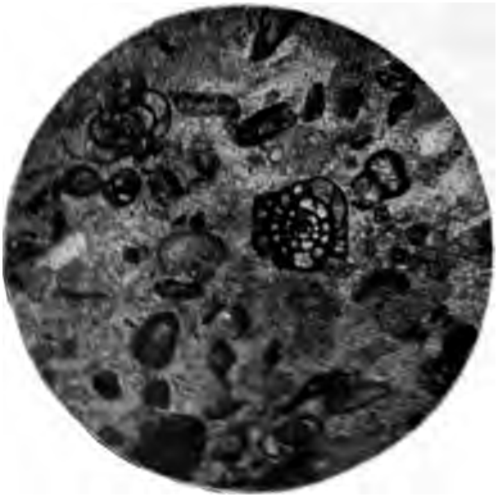


FIG. 30. ENDOTHYRA LIMESTONE: CARBONIFEROUS. DOVEDALE, DERBYSHIRE. ×24. *Original.*

of especial interest, since they are characteristic of certain strata of much later date, namely, *Amphistegina* (from Bristol) and *Nummulites* (from near Namur, Belgium).

In some parts of the world we meet with a series of sedimentary rocks which are partly homotaxial with the Carboniferous strata, and partly with the [illegible] group of the Permian which is so extenin elucidating the Liassic foraminiferal fauna. An important find was made by Haeusler some years ago in the sandy marls (Oxfordian) of the Canton Aargau, in Switzerland, where a remarkable series of Foraminifera was discovered from the zones of *Ammonites transversarius* and *A. bimammatus.* This fauna comprised many nodosarian forms, but the larger part consisted of arenaceous genera, the existing forms of which usually indicate deep-water conditions. To mention some of the arenaceous genera met with, we may quote *Psammosphæra*, *Astrorhiza*, *Rhabdammina*, *Marsipella*, *Hyperammina*, *Lituola*, *Reophax*, *Haplophragmium*, *Haplostiche*, *Placopsilina*, *Trochammina*, *Ammodiscus*, *Hormosina*, *Webbina*, *Thurammina*, *Textularia*, *Bigenerina*, and *Valvulina.*

In the Oxford Clay of Weymouth, in England, the porcellanous type *Nubecularia* is frequently found covering the exterior of large shells, such as *Gryphæa*, with their ramifying tests.

The Kimeridge Clay is also prolific in Foraminifera at some localities, the prevailing genera being *Cristellaria* and *Pulvinulina.*

The Tithonian beds (Portlandian) of the Continent have yielded many interesting genera, notably *Involutina*, *Haplophragmium*, *Valvulina*, *Nodosaria*, *Frondicularia*, and *Cristellaria.* The facies appears to be a transitional fauna between the older and the newer Mesozoic strata.

The Neocomian and Aptian formations, both in England and in Germany, contain a comparatively sparse foraminiferal fauna, owing to the lithological the species appear to be of Permian age. Quite recently Spandel has, however, considerably added to the Zechstein foraminiferal fauna, and cites the following additional genera: *Hyperammina*, *Cornuspira*, *Lingulina*, *Frondicularia*, *Vaginulina*, *Marginulina*, *Geinitzella* (afterwards changed to *Geinitzina*), and *Lunucammina*.[1]

By the presence of forms like *Lingulina*, *Frondicularia*, and *Vaginulina* we are reminded of the prevalent characteristics of the Mesozoic foraminiferal faunas, in which the above-named genera are conspicuous in increasing abundance as we ascend the geological scale. The prototypes of these hyaline forms may have been the somewhat irregular and subarenaceous isomorphs found in the Carboniferous System which have been described by Brady under the generic names of *Stacheia* and *Nodosinella*.

The Triassic System as a rule is not prolific in Foraminifera. The Muschelkalk has yielded organisms in some abundance belonging presumably to the genera *Globigerina* and *Orbulina*. Gümbel has described a fauna from the oldest strata of the Bunter Sandstone in the Alps, which is remarkable from the fact that it includes two species of *Endothyra*, a genus which otherwise is unknown outside the Carboniferous System. Associated with *Endothyra* are the following genera, *Ammodiscus*, *Valvulina*, *Bulimina*, and *Lingulina*. Several genera, including *Nodosaria*, *Polymorphina*, and *Pulvinulina*, have been figured by the last-named author from the Upper Trias and Rhætic of the Southern Alps.

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[1] *Lunucammina* is a modification of *Geinitzina* in which the vertical axial depression exists only on one side, the other side forming, so to speak, a rounded dorsal surface.

In the topmost or passage beds of the Triassic series—the Rhætic—in England a somewhat rich foraminiferal fauna was recently found by the writer, in the marls, black clay, and shelly limestones of Wedmore, in Somerset. The marly strata are there filled with several species of *Stacheia* and *Nodosinella*. The black clay yielded *Reophax*, *Haplophragmium*, *Ammodiscus*, *Bulimina*, and *Truncatulina*. Two hyaline types, *Nodosaria* and *Marginulina*, were found in the limestones of the same series.

In considering the foraminiferal facies of the Jurassic system we shall note the general absence of any of the larger Foraminifera, which in other formations often play an important part in forming massive limestones. In the strata which form the Liassic beds the Foraminifera are for the most part found distributed, sometimes in great abundance, in certain zones of the marls and clays of the series ; but they are usually quite microscopic and nearly always in a small proportion to the bulk of the rock. Many of the genera continue upwards into the Lias from the Upper Palæozoic strata, such as *Ammodiscus*, *Haplophragmium*, *Valvulina*, and *Stacheia*. The most noteworthy feature, however, is the great influx of hyaline genera and species, the allied types of which now only flourish in warm, temperate, and tropical seas, such as the large *Cristellariæ*, and the flattened forms of the same genus, which also bear some relationship to *Vaginulina*, and which D'Orbigny described under the quasi-generic name of *Planularia*. The tiny discoidal *Ammodiscus*, so common in the Carboniferous System, is found profusely in some Liassic clays; and a related form, though distinct in internal structure, *Involutina*, here makes its first appearance, and continues nearly to the top of the Oolitic series (Portlandian), where it finally disappears, or perhaps gives rise to the more specialised *Orbitolinæ* of subarenaceous structure, which make their appearance in Neocomian strata (*O. lenticularis* and *O. discoidea*). Certain of the porcellanous forms, as *Spiroloculina* (often arenaceous also) and *Miliolinæ*, are met with in some abundance in the Lias. The hyaline genera are represented by *Nodosaria*, *Marginulina*, *Cristellaria* (of which the planulate forms are much in evidence), and *Polymorphina*; the rotalines chiefly being *Truncatulina* and *Pulvinulina*.

In the Oolitic period the Foraminifera were somewhat similar in character to those of the Lias, but show a considerable increase in the number of genera and species, whilst towards the top of the series the fauna shows a certain likeness to those of the Neocomian and Cretaceous strata. Our knowledge of the Foraminifera from the Jurassic system of Germany and France is due to the indefatigable labours of Terquem, whilst Wisniowski and Uhlig have described Polish and Russian deposits containing Foraminifera. The Jurassic strata of England have not, perhaps, received so much attention as they deserve, but Brady and others have done some work in elucidating the Liassic foraminiferal fauna. An important find was made by Haeusler some years ago in the sandy marls (Oxfordian) of the Canton Aargau, in Switzerland, where a remarkable series of Foraminifera was discovered from the zones of *Ammonites transversarius* and *A. bimammatus*. This fauna comprised many nodosarian forms, but the larger part consisted of arenaceous genera, the existing forms of which usually indicate deep-water conditions. To mention some of the arenaceous genera met with, we may quote *Psammosphæra*, *Astrorhiza*, *Rhabdammina*, *Marsipella*, *Hyperammina*, *Lituola*, *Reophax*, *Haplophragmium*, *Haplostiche*, *Placopsilina*, *Trochammina*, *Ammodiscus*, *Hormosina*, *Webbina*, *Thurammina*, *Textularia*, *Bigenerina*, and *Valvulina*.

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The Neocomian and Aptian formations, both in England and in Germany, contain a comparatively sparse foraminiferal fauna, owing to the lithological conditions of the beds, which comprise a large proportion of glauconitic sandy strata. They bear evidence, however, in the glauconitic granules, or casts, to the former existence of these organisms in prodigious abundance.

The Neocomian (Urgonian) beds of the Isle of Wight, especially the argillaceous and marly strata known as the Atherfield Clay, contain many minute species of *Cristellaria* and *Pulvinulina*, which occur in the succeeding beds of the Albian or Gault in other parts in considerable numbers and better developed in point of size.

The Aptian beds of Surrey, locally known as the Bargate Stone Beds, contain a rich and varied foraminiferal fauna, partly due to the fact that it comprises some species which have been derived from pre-existent strata in the neighbourhood, of Oolitic age.

At Sandgate the clays of Aptian age also contain many species which bear a strong resemblance to a Lower Gault facies.

The Aptian beds of Switzerland have also proved to be productive in Foraminifera, and it is in this formation that the *Orbitolina lenticularis*, previously mentioned, occurs, where it forms a more or less massive rock called the *Orbitolina* Limestone.

By far the richest foraminiferal beds of the Lower Cretaceous are those of Albian age, and the Gault clays of England, France, and Germany have furnished several hundred species. Reuss has very thoroughly described the foraminiferal facies of these beds for Germany, and Berthelin for France. An idea of the profusion of Foraminifera in this formation may be gathered from the fact that in this country, from the Folkestone cliffs alone, the writer has described 265 species, comprised within 43 genera. The Gault fauna embraces among its commoner types such genera as *Nubecularia*, *Miliolina* (Upper Gault), *Haplophragmium*, *Ammodiscus*, *Textularia*, *Gaudryina*, *Tritaxia* (most frequent in the Upper Gault), *Bulimina* (chiefly in the Upper Gault), *Nodosaria*, *Frondicularia*, *Rhabdogonium* (Upper Gault), *Vaginulina*, *Cristellaria*, *Globigerina*, *Anomalina*, and *Pulvinulina*.

The Red Chalk of Yorkshire and Norfolk is apparently the equivalent of certain zones of the Upper Gault and Greensand, although so lithologically distinct. This is especially borne out by a comparison of the Foraminifera.

The Greensand of New Jersey, a formation of equivalent and later ages to those just named, has yielded an abundant foraminiferal fauna, and many of the species have developed to a comparatively large size. They have been studied by Reuss, Woodward, and Bagg, the latter author having largely added to the list of late years.

The Upper Greensand in Devonshire contains a chert bed, which in places is almost entirely composed of the large tests of *Orbitolina concava*; and the gravels in the neighbourhood of Haldon Hill consist largely of this foraminiferal rock. The calcareous shells are in this chert-rock entirely replaced by silica. As a rule, however, the Upper Greensand is rather poor in microzoa, and very little beyond *Haplophragmium* and *Globigerina* is found in this formation.

The so-called 'Cambridge Greensand' is a *remanié* bed with derived fossils, and even the larger part of the Foraminifera, which are abundant therein, may owe their origin to the waste of beds equivalent to the Upper Gault.

From the Cenomanian beds of Bohemia an interesting and abundant foraminiferal fauna has been obtained by Perner.

The Chloritic marl of England contains a small fauna, for the larger part possibly derived and consisting mainly of arenaceous foraminifera.

The Chalk Marl of England, and its equivalent, the Lower Planer limestone, in Westphalia and Hanover, contain a rich assemblage of species, and have a large percentage of forms common to the Upper Gault and Red Chalk; this points to the long continuance of the conditions which existed in earlier times.

The Grey Chalk of the South of England is not very productive in Foraminifera, and the specimens are small and apparently starved.

In the Turonian series the 'Melbourne Rock' is largely composed of Foraminifera, which may be seen in thin sections; and its equivalent in Germany, the Upper Planer Limestone, also yields an abundant fauna. The 'chalk without flints' of this country is not so rich in Foraminifera as the same ceeding beds, but they have been shown to contain a considerable number of distinct forms.

The 'Chalk rock' or zone of *Holaster planus* is in England largely constituted of Foraminifera (see fig. 4), principally *Textularia globulosa* and *Globigerina cretacea* and *marginata*, and it is here we seem to obtain a first glimpse of the different and varied microzoic fauna so characteristic of the Upper Chalk.

The 'Micraster Chalk, with flints,' is in most of its zones largely constituted of foraminiferal shells, and some forms, like *Textularia globulosa* and *Bolivina strigillata*, are especially characteristic of this part of the series. At certain levels the chalk is partly replaced by phosphate of lime, and this mineral change, to a great extent, has the effect of preserving the shells. The flints of this series, when hollow, are found to contain a siliceous powder, sometimes called 'Flint-meal,' which is largely made up of the casts or replacements of Foraminifera and other organisms, such as Ostracoda, polyzoa, and also sponge-spicules. The following species, among others, are characteristic of the Upper Chalk fauna, including those mentioned above: *Textularia decurrens*, *T. serrata*, *Gaudryina Jonesiana*, *Marginulina elongata*, *Cristellaria Gaudryana*, *Flabellina rugosa*, *F. ornata*, *F. Baudouiniana*, *Polymorphina acuminata*, *Truncatulina Clementiana*, *T. Lorneiana*, and *Rotalia exsculpta*.

The White Chalk of the Island of Rügen has een productive in Foraminifera, and Marsson has described the fauna in detail. Wright has dealt with the Irish foraminiferal chalk, and the material on which his work has been based is the flint meal found in the pot stones or paramoudras of Ireland, the chalk itself being usually so hardened by the proximity of the basalt flows that it is impossible to deal with it like our ordinary soft writing chalk.

In Australia the borings into the cretaceous of the central territories have given Howchin opportunity to record a fairly rich fauna, comprising the genera *Sigmoïlina*, *Hyperammina*, *Reophax*, *Haplophragmium*, *Placopsilina*, *Thurammina*, *Ammodiscus*, *Bigenerina*, *Verneuilina*, *Gaudryina*, *Lagena*, *Nodosaria*, *Lingulina*, *Frondicularia*, *Vaginulina*, *Marginulina*, *Cristellaria*, *Polymorphina*, *Spirillina*, *Patellina*, *Discorbina*, *Anomalina*, *Truncatulina*, and *Pulvinulina*.

The Chalk of Maestricht is rich in Foraminifera, and the facies there met with is peculiar, for there is a large preponderance of genera which are characteristic of Eocene and Miocene strata elsewhere, as, for example, *Orbitolites*, *Calcarina*, *Amphistegina*, *Operculina*, and *Orbitoides* (sub-genus *Lepidocyclina*).

In the London Basin Foraminifera occur in nearly all the members of the Lower Eocene. The Thanet sands in their more argillaceous strata in Kent have afforded many species, which have been described by Burrows and Holland. The Foraminifera show a marked difference in the facies from that of the highest mesozoic strata, but resemble in many points the Liassic series, and also parts of the Gault, in containing a large proportion of planulate *Cristellariæ*, which points to similarity in the conditions of habitat. The Thanet beds also contain many Rotalines and the beaded form of *Cristellaria* (*C. fragraria*), which are later found in the London Clay of London and Sheppey in some abundance.

The clays of the Woolwich and Reading series, consisting as they do of estuarine muds with much ferruginous material, have not yielded more than a few starved species, mainly of Rotalines, which the author has noticed in certain samples from Dorsetshire.

In the London Clay, both in the London and Hampshire Basins, we find a rich and varied foraminiferal fauna. This formation is now held by some geologists to belong to the Middle rather than the Lower Eocene period; the presence and distribution of the Nummulites and other Foraminifera in equivalent strata elsewhere, however, do not bear out this assumption. The equivalent strata to the London Clay in the Paris Basin are the Ypresien beds, containing *Nummulites planulata.*

The Middle Eocene also embraces the Bracklesham Beds, which in the South of England contain a stratum with *Nummulites lævigatus*, associated with a smaller species, *N. scabra; N. variolaria* also occurs in the upper part of this series. Besides these Nummulites there are a few species of *Biloculina*, *Miliolina*, and some Rotalines, as *Discorbina* *trochidiformis*. Just off Selsey a patch of partial submerged rocks called the 'Mixens' occurs, whi is a hard foraminiferal bed composed almost entirel of *Miliolina* and *Alveolina*, and which was used i building the old Selsey churchyard wall.

The 'Calcaire grossier' beds of the Paris Basin are of the same age as those just described, and contain a similar foraminiferal fauna, with the addition of *Orbitolites*. The preponderance of *Miliolina* (*Pentellina saxorum* and other species) in this rock, which has been extensively utilised as a building stone for Paris, has given rise to its name 'Miliolitic Limestone' (fig. 31).

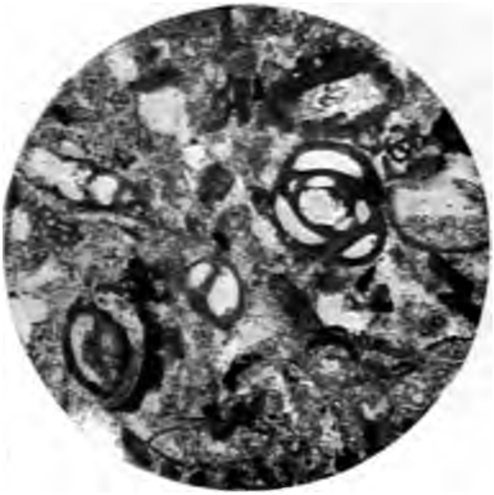


FIG. 31.—MILIOLINA LIMESTONE (M. TRIGONULA); EOCENE. PARIS BASIN. *Original.*

The Upper Eocene of the Hampshire Basin contains, in the Barton Beds, certain strata which yield in abundance the small species of nummulites, N.

elegans and *N. variolaria*, and these species also occur in the equivalent beds, the 'Sables Moyens' of the Paris Tertiary.

The limestones formed chiefly of nummulites are developed to a large extent on the Continent, and they form a broad but interrupted series extending right across the region of the Old World. In the South of France, at Biarritz, the Nummulitic series is more than 3,000 feet thick. In the South and South-East Alps the Nummulitic limestone series is well developed, and they are associated with *Alveolina*. In the Northern Apennines the Middle Eocene contains *Nummulites Biarritzensis*, *N. Lamarcki*, *N. Lucasana*, *Assilina*, *Operculina*, and *Alveolina*; the Upper Eocene contains *Nummulites striata*, *N. Tchihatcheffi*, and *Orbitoides radians*.

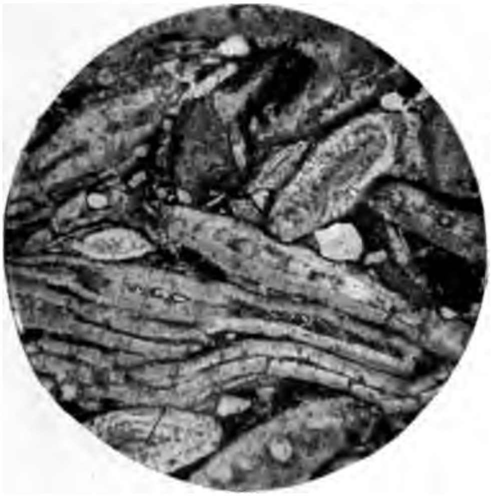


FIG. 32.—HETEROSTEGINA LIMESTONE; TERTIARY, WADI DARA, EGYPT. × 16.

The Kressenberg inlier, in Bavaria, consisting o the Lower Nummulitic series, has yielded a very rich foraminiferal fauna. The nummulites there and in Austria are of an exceptionally large size. The Kressenberg series also contains numerous species of *Orbitoides*, which, from that locality, have been principally worked out by Gümbel.

The Nummulitic series in Egypt constitutes the greater part of the Eocene limestones. It is divided into three stages, the Libyan or Lower Eocene, the Mokattam or Middle Eocene, and the Bartonian or Upper Eocene; each of these contains certain characteristic groups of nummulites, which are of much value in the determination of the various horizons. The nummulites attain their greatest development and abundance in beds of Middle

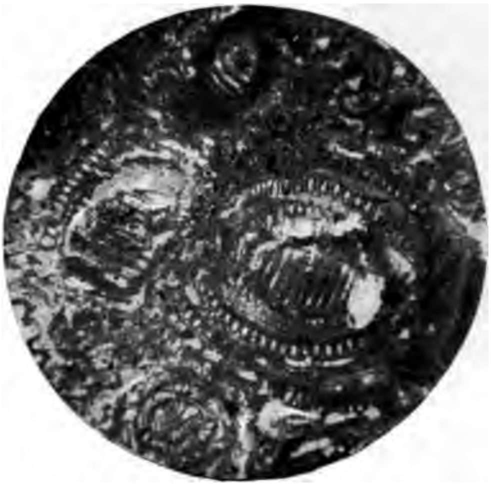


FIG. 83.—ALVEOLINA LIMESTONE; EOCENE, FARAFRA, EGYPT. × 16.

ocene age, as they do in many other places. ssociated with these are other genera, such as *eterostegina* (fig. 32), *Operculina*, and *Alveolina* . 33), and sometimes by their abundance they m limestones almost wholly consisting of one ticular form.

The Eocene nummulitic beds extend into the ai Peninsula (fig. 34), and thence to other parts

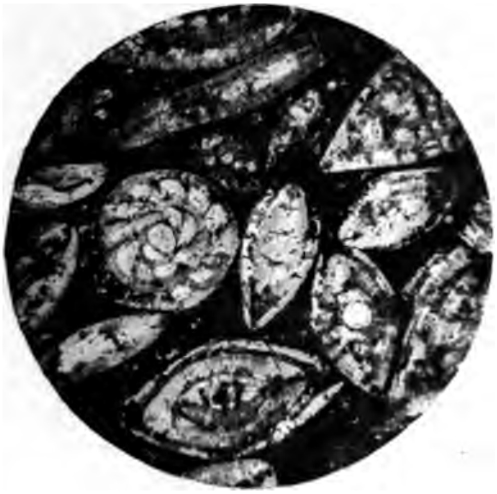


Fig. 34.—Nummulitic Limestone; Eocene, Jebel Abyad, Sinai. × 16.

sia. In India the nummulites and other Forami- ra form massive beds of limestone, often con- uting the greater part of some of the mountain ges. By a process of folding and crumpling these s of limestone have been elevated, so as to form e of the highest mountain crests, attaining in ne cases an altitude of 16,000 feet. The lower part the Nummulitic Series in Sind is represented by the Ranikot beds, containing *Nummulites spira*, *N. irregularis*, and *N. Leymeriei*; and this is followed by the Kirthar Group, with *N. Garansensis*, also a European species, and *N. sub-lævigata*, apparently confined to India. The nummulites are here associated with large species of *Alveolina* and *Orbitoides*.

In the Oligocene strata in Germany the beds are often richly foraminiferal, and the Septarian Clays of Hermsdorf and other localities has yielded a prolific fauna. In this country the Oligocene is not so productive, since the beds are for the main part of fresh-water or fluvio-marine characters. From the Isle of Wight a small series, chiefly represented by *Miliolina* and *Polymorphina*, has been obtained by the writer. The Malta tertiary beds are in part of Oligocene age, and many of the beds there

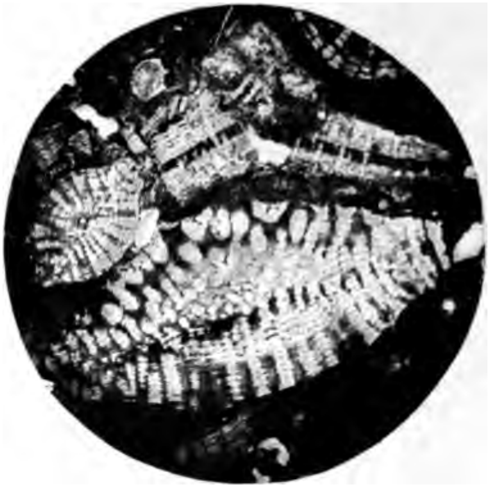


Fig. 35.—Orbitoides Limestone; Lower Miocene, Christmas Island. × 10.

s well as in Jamaica, in the West Indies, contain n abundance of *Orbitoides*.

The Miocene System in the Vienna Basin is very oductive of Foraminifera, and a rich assemblage has en described by D'Orbigny, and later by Karrer. e Miocene Clays and sands of Muddy Creek and ount Gambier, in Victoria, Australia, have yielded abundant fauna, and the specimens are well grown and comparable in many respects with the specimens from Jamaica, as well as those of Java and Christmas Island (fig. 35). In the United States the Miocene of Maryland and Virginia have been proved to be rich in these organisms. The upper series in Malta, which are of Miocene age, contain a vast number of a large variety of *Heterostegina*. In Italy the richly fossiliferous tertiaries are partly

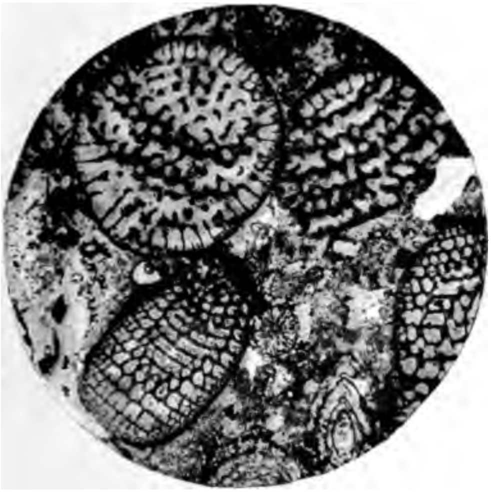


FIG. 36.—CONULITES LIMESTONE; TERTIARY, EGYPT. × 12.

of Miocene age, but there the Pliocene strata are mostly in evidence, containing an abundant foraminiferal fauna. A limestone of foraminiferal origin, chiefly consisting of *Conulites*, and doubtfully of Miocene age, has lately been described from the neighbourhood of Cairo (fig. 36).

The Older Pliocene of Italy, as described by Costa, Terrigi, Fornasini, and Egger, has a remarkable fauna, and the interesting deposit of blue sandy clay at St. Erth, Cornwall, as elucidated by Millett, is in many respects comparable with those beds, especially with the deposits at Bordighera.

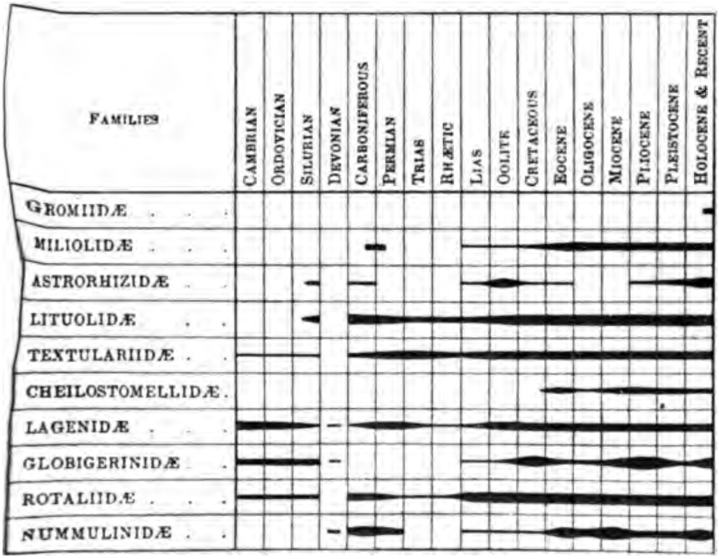
The Pliocene of England, in East Anglia, has been productive of an extensive series of distinct forms, both from the Red and the Coralline Crags.

The Tertiary clays of California are possibly of Pliocene age, and also the richly fossiliferous *Globigerina*-marls of Barbados, although the latter deposits have certain affinities with Miocene and even Oligocene faunas.

The foraminiferal deposit of Wanganui, in New Zealand, a green sandy shell-marl, also calls for special note, on account of its richness in these fossils.

Up to the top of the Pliocene system the various tertiary faunas, although represented for the main part by species now living in various parts of the ocean, are yet differentiated from the foraminiferal facies still existing near those localities by the influences which changes of climate and alteration in the coast lines or the trend of the mud lines, their chief feeding ground, have borne upon them.

The Post-pliocene and Estuarine deposits of the Raised Beaches and the recently emerged tracts of land have little to show in their facies of a different character, excepting what might result from slight changes of climate or in the nature of the sea-floor, evidenced in the greater or less development of the foraminiferal shells.



CHAPTER XVIII

THE GEOGRAPHICAL DISTRIBUTION OF FORAMINIFERA, WITH REMARKS ON THE ACCOMPANYING CONDITIONS OF TEMPERATURE, DEPTH, AND GENERAL ENVIRONMENT

FORAMINIFERA are largely influenced by the temperature of the water in which they live, and therefore it will not be surprising to find that different latitudes have their own peculiar assemblages of species, and that the foraminiferal faunas of the colder regions are in many respects unlike those of the warmer areas. This difference is naturally more noticeable in the case of bottom-living species from *shallow* water, for the surface waters of high and low latitudes present a wider range of temperature than the water of similar areas at greater depths. Then, again, the distribution of the equatorial and other warm surface currents has a marked influence on the surface-living organisms, as will be seen later on.

Some genera, and even species of living Foraminifera, are cosmopolitan, like *Miliolina seminulum* and *Nonionina depressula*, which are found in almost equal abundance on the shores of the British Islands and in the equatorial waters of the Pacific. Others again are restricted to certain areas, as, for example, some of the larger *Nodosariæ*, which are found in the West Indies; *Alveolina*, recorded from the equatorial parts of the Indian and Pacific Ocean; or *Cycloclypeus*, which is found in a few widely separated localities, off Borneo, Solomon Islands, the Fijis, and Funafuti.

In studying the question of distribution we shall find that each distinct kind of sea-bottom contains its own group of organisms, microscopic and otherwise. To take the well-known example of the *Globigerina* Ooze, this for the most part, in typical samples, is composed of the shells of the pelagic or surface-living Foraminifera, viz. *Globigerina*, accompanied by other pelagic genera, as *Sphæroidina* and *Pulvinulina*, associated frequently with an admixture of bottom-living forms, such as *Reophax*, *Cristellaria*, *Truncatulina*, and *Rotalia*. In order to gain a clear idea of the association of Foraminifera in the various kinds of deposits now being formed either in deep oceanic areas or on the shallower continental slopes, we shall now proceed to select typical examples of such deposits from high and low latitudes.

The two principal types of foraminiferal deposits are the *Pelagic Deposits*, formed in deep water, far removed from land, and the *Terrigenous Deposits*, formed in moderately deep and shallow water closer to land masses.

The bottom areas of deep-sea deposits have a temperature below 40° F., but little subject to variation, and then only when in proximity to the 100-fathom line. An idea of the range of temperature in the water of tropical areas may be seen by the observations made by the 'Challenger' in the South Atlantic Ocean near the equator. Whilst the temperature of the surface water varies between 76° and 80°, at a depth of 300 fathoms it is only 40°; and in the deeper parts of the same area it is as low as 32·4°.

PELAGIC DEPOSITS.

Globigerina Ooze is the name which was given to the fine, sticky, calcareous mud brought up by the sounding apparatus when testing the ocean contours in order to lay the cables for the electric telegraph. It owes its distinctive name to the comparatively large proportion of shells of *Globigerina bulloides* and other pelagic Foraminifera of which the deposit largely consists. The dried ooze varies from white, yellow, or rose colour to brown or grey, and it is, obviously, of a darker tint when wet. Those deposits which contain more than 30 per cent. of material directly due to the shells of *Globigerina* were classed by the 'Challenger' naturalists as *Globigerina* oozes. Besides the pelagic Foraminifera this ooze generally contains a variable quantity of the minute algal bodies known as coccospheres and coccoliths, and rhabdospheres and rhabdoliths, together with a small proportion of amorphous, calcareous, or earthy matter.

The *Globigerina* oozes, according to the 'Challenger' statistics, range in depth from 400 to 2,925 fathoms; but they occur chiefly and typically within the limits of 1,500 to 2,500 fathoms.

Globigerina ooze is one of the most widely distributed of the marine deposits, and its importance as a recent foraminiferal deposit may be conceived from the fact that it covers an area of the ocean floors estimated at 49,000,000 square miles. The pelagic species found in these oozes are—

Globigerina sacculifera, Brady;
G. æquilateralis, Brady;
G. conglobata, Brady;
G. dubia, Egger;
G. rubra, D'Orbigny;
G. bulloides, D'Orbigny;
G. inflata, D'Orbigny;
G. digitata, Brady;
G. subcretacea, Chapman MS. (=*cretacea* of recent deposits);
G. Dutertrei, Brady;
Orbulina universa, D'Orbigny;
Hastigerina pelagica, D'Orbigny sp.;
Pullenia obliquiloculata, Parker and Jones;
Sphæroidina dehiscens, Parker and Jones;
Candeina nitida, D'Orbigny;
Cymbalopora (Tretomphalus) bulloides, D'Orbigny sp.;
Pulvinulina Menardii, D'Orbigny sp.;
P. tumida, Brady;
P. canariensis, D'Orbigny sp.;
P. Micheliniana, D'Orbigny sp.; and
P. crassa, D'Orbigny sp.

The influence of surface temperature on the pelagic fauna is seen in the fact that *Globigerina* ooze is especially developed in those areas where the surface of the sea is traversed by warm currents; and where it is found in the Arctic regions is principally in the track of the Gulf Stream. Therefore, as might naturally be expected, *Globigerina* ooze is found more abundantly in tropical areas and at greater depths than in the higher latitudes in colder areas.

To take as an example a specimen of *Globigerina* ooze from a comparatively high latitude in the northern hemisphere, the following sounding from the 'Challenger' series may be quoted:—

'*Station* 76.—July 3, 1873. Lat. 38° 11′ N., long. 27° 9′ W. Off the Azores. Depth, 900 fathoms; bottom temperature, 4·2° C. (39·5° F.); *Globigerina* Ooze.

'Contains small stones, pteropods, and a good deal of coarse stuff. In addition to *Globigerina* and the pelagic *Pulvinulinæ* the more noteworthy species belong to the genera *Biloculina*, *Miliolina*, *Cristellaria*, *Truncatulina*, *Rupertia*, *Haplophragmium*, *Trochammina*, and *Hormosina*.'

The following may be quoted as an example of a *Globigerina* ooze from a high latitude in the southern hemisphere:—

'*Station* 146.—December 29, 1873. Lat. 46° 46′ S., long. 45° 31′ E. Depth, 1,375 fathoms; bottom temperature, 1·5° C. (34·7° F.); *Globigerina* ooze.

'A greyish-white mud with fragments of echinus tests, spines, &c. Chiefly made up of *Globigerina bulloides* and *G. inflata*. Of the surface *Pulvinulinæ* the comparatively uncommon *P. crassa* appears to preponderate in this locality. Arenaceous Foraminifera are almost entirely wanting. The occurrence of two or three specimens of *Clavulina communis* forms perhaps the most interesting feature in the dredging.'

As a typical specimen of *Globigerina* ooze from a position nearly under the equator in mid-ocean we may quote the 'Challenger' sounding.

'*Station* 271.—S. Pacific. Lat. 0° 33′ S., long. 151° 34′ W. Depth, 2,425 fathoms; bottom temperature, 1·0° C. (33·8° F.)'

'This deposit contains a large proportion of Radiolaria.

'The larger Foraminifera were chiefly of two species, *Pullenia obliquiloculata* and *Pulvinulina tumida*. All the common varieties of *Globigerina* were present, together with such genera as *Lagena*, *Nodosaria*, *Truncatulina*, and *Nonionina*; but perhaps the species most characteristic of the locality were *Pulvinulina favus* and *Ehrenbergina serrata*.'

Pteropod Ooze.—The foraminiferal fauna of a pteropod ooze largely depends upon the position of the deposit, whether in proximity to land or far removed from any coast line. This is shown by the following soundings taken by the 'Challenger,' in which, in the one case, where the deposit was formed at a considerable distance from the land, the fauna was restricted to an almost purely pelagic series, chiefly of *Globigerinæ*, whilst, on the other hand, the series obtained from a rich calcareous, pteropod ooze, from moderately deep water, not far from land masses, yielded no less than 177 species, mainly of bottom-living Foraminifera.

'*Pteropod Ooze.*—Station 337. March 19, 1876. South Atlantic. Lat. 24° 38′ S., long. 13° 36′ W. Depth, 1,240 fathoms; bottom temperature, 2·5° C. (36·5° F.) The washed material consisted chiefly of Pteropod shells, and the Foraminifera present belonged exclusively to surface species. Amongst the latter are most of the known forms of *Globigerinæ* and of pelagic *Pulvinulinæ*, together with a considerable number of *Hastigerinæ* and *Candeinæ*.'

'*Pteropod Sand.*—Station 24. March 25, 1873. Off Culebra Island, N. of St. Thomas's, West Indies. Depth, 390 fathoms. White material, with large numbers of Pteropod shells. Very rich in Foraminifera, particularly in the larger forms of *Nodosariinæ* and *Textulariinæ*, and in arenaceous types. Of the former the genera *Nodosaria*, *Lingulina*, *Frondicularia*, and *Cristellaria* are represented by remarkably fine examples; the Textularian group contributes specimens of *Textularia*, *Pavonina*, *Bigenerina*, *Verneuilina*, and *Clavulina*, which are equally noteworthy, whilst the Arenacea furnish *Rhabdammina*, *Hyperammina*, *Cyclammina*, and *Ammodiscus*, together with many of the smaller forms; and the Porcellanea are conspicuous in *Orbiculina* and large *Biloculinæ*.'

This latter deposit also contains many pelagic species not enumerated in the above diagnosis given by Dr. Brady. The deposit, however, might equally well be classed with terrigenous deposits, on account of its proximity to the land.

Red Clay.—The Foraminifera of the Red Clay deposits of the 'Challenger' collection have been enumerated by Brady, who records 182 species. The fauna, as a whole, consists largely of pelagic species, with an admixture of arenaceous deep-sea forms. A conspicuous feature of some of these deposits is the abundance of delicate-shelled *Lagenæ*, many of them exceedingly beautiful in their superficial ornament. Some of the deeper *Globigerina* oozes, approaching the Red Clays in character, from the Pacific Ocean in the neighbourhood of the Ellice Islands, have been found by the author to contain similar delicate Foraminifera of the same genus.

Certain of the *Miliolinæ* of the Red Clay deposits have their calcareous tests replaced by a thin siliceous film.

TERRIGENOUS DEPOSITS.

The variously coloured Blue, Red, and Green Muds which are found near the coast lines of continents or other land masses, and which almost directly owe their origin to the wearing down of the land surfaces by rivers and the coast line by the action of the waves and tide, possess a foraminiferal fauna somewhat peculiar to these accumulations. There is a marked scarcity of calcareous material to be frequently noticed in the conditions under which they are formed, and this, consequently, has a direct effect on the shell-structure of the organisms found there, showing a prevalence of certain generic types best fitted for those particular conditions.

In the terrigenous deposits we find, for example, the thin-shelled Foraminifera, as *Lagena*, *Bolivina*, *Bulimina*, and certain small forms of *Globigerina* usually predominant, whilst porcellanous forms are restricted to those which have a thin shell-wall, or one constructed of fine arenaceous material.

For an example of a terrigenous deposit of this description we may quote a sample collected by the U.S. Fish Commission steamer 'Albatross' east of Mariato Point, Gulf of Panama. This was a Green Mud dredged from 695 fathoms. The chief foraminiferal contents, enumerated by Dr. Axel Goës, are as follows: *Haplophragmium canariense*, D'Orb. sp.; *Textularia sagittula*, var. *cuneiformis*, D'Orb.; *Bolivina punctata*, D'Orb.; *Bulimina ellipsoides*, Costa; *Cheilostomella ovoidea*, Reuss; *Lagena marginata*, W. and B.; *Nodosaria raphanus*, Linné sp.; *Uvigerina pygmaea*, D'Orb.; *U. Auberiana*, D'Orb.; *Truncatulina Wuellerstorfi*, Schwager sp.; *T. mundula*, Brady, Parker, and Jones; *Rotalia Soldanii*, D'Orb. sp.; and a few pelagic species, as *Globigerina dubia*, Egger.

The Greensands largely consist of green granules, which on minute examination prove to be casts of Foraminifera in Glauconite. In some samples of Greensands the tests still remain, but more often they speedily decay and only the cast is left. The following is Dr. Brady's description of the noteworthy 'Challenger' sounding of Greensand off ydney at 410 fathoms. The deposit resembles a ey ooze:—

'The organisms contained in the material from is station are infiltrated in a very remarkable anner with a siliceous mineral (Glauconite), and y decalcifying with weak acid perfect casts of the hambers of most of the Foraminifera of a common *lobigerina* ooze may be obtained. The list of pecies is a tolerably long one, and contains an dmixture of some shallow-water forms, but otherise presents nothing very distinctive.'

In consideration of the fact that Greensands ccur as important foraminiferal deposits in various eological systems it is interesting to note that at e present day these deposits are never found deeper an 900 fathoms, whilst their average depth is 19 fathoms. For the formation of these deposits it ems essential that they should be within the innence of marine currents by which the sands are set motion. Extensive deposits of Greensands are met ith off the coast of California, the east coast of . America, the Cape of Good Hope, to the east Africa, and off the coasts of Portugal, South merica, Japan, and Australia.

The deposits forming round coral islands in the acific and Indian Oceans are known as *Coral Muds* d *Coral Sand*. They are largely made up of the ganisms which live in great numbers in such localis, as, for example, the Calcareous Algæ, various raminifera, Alcyonarians, Corals, Molluscs, Polya, Annelids, and Echinoderms.

These deposits of Coral Mud and Sand only differ from one another in the former containing a larger percentage of fine amorphous matter, chiefly carbonate of lime, whilst the coral sand, occurring generally at less depths, consists of organic particles, with a small or almost inappreciable quantity of fine material.

The Coral Sands, forming on the slopes and shoals of the reef, are sorted and sifted by wave action, and consolidated sometimes by the deposition of calcareous cement, or by the growth of Lithothamnion and encrusting Foraminifera; the latter often covering patches of the sand measuring as much as five inches across, and due to the continuous growth of one particular organism—the remarkable *Polytrema planum* of Carter.

The proportion of the Coral Sand actually due to the remains of corals is usually very small, and therefore the term must be regarded as indicative of association rather than of composition.

The foraminiferal fauna of the Coral Sands presents many features of interest, and the assemblages formed under the conditions associated with reef-building organisms often have a distinct character by themselves. We may find under favourable and variable conditions, such as these, an extensive series of foraminiferal forms, many of the shells being of great delicacy and beauty.

One of the most remarkable foraminiferal deposits of Coral Sand was dredged from Raine's Islet, Torres Strait, at 155 fathoms, by the nger.' This material has yielded in the of Dr. Brady and others no less than 269 and varieties of the Foraminifera alone. ning this Brady says: 'Amongst the many rms are the following:—*Lagena spiralis*, *Hertwigii*, and *Lagena Schulzeana; Cristel-mmata* and *Cristellaria tricarinella; Sagraina*; *Pulvinulina procera* and *Pulvinulina ersii; Truncatulina præcincta, Rupertia sta, Textularia crispata, Textularia folium, extularia transversaria; Pavonina flabelli- Chrysalidina dimorpha, Spiroplecta annectens, lina calabra, Cornuspira sulcata*, and *Cornu-rinata*.'

dredgings made by the Coral Reef Expedi-und Funafuti, in the Pacific, have yielded n more extensive fauna than the above, for mber of species found there is over 300, t which many large reef-living species are uous, such as *Carpenteria rhaphidodendron*, *ma planum*, and *Cycloclypeus Carpenteri*. ach sands of the coral islands in the Pacific etimes entirely composed of a few genera of nifera in extraordinary abundance, such as *tegina Lessonii, Heterostegina depressa, Poly-miniaceum, Tinoporus baculatus, Orbitolites nata, Carpenteria monticularis, Gypsina globu-lcarina hispida*, and *Miliolina reticulata*.

Shore Sands of temperate and colder areas fauna peculiar to themselves. The dis-n of the various genera and species is dependent upon several factors in their conditions of existence, such as the surface and bottom temperatures of the water; the presence of warmer or colder currents, as, for example, in the Faröe Channel, which, being on the border line between the warm and cold areas, presents a special feature in its foraminiferal fauna; the proximity of limestone cliffs; and the nature of the surrounding sea bottom. As it has already been remarked, a certain proportion of species are cosmopolitan in their habits, being found alike in shallow and deep water; and in both high and low latitudes. On this statement, however, there must be placed a certain amount of reservation, for there is generally some varietal difference even in these ubiquitous forms when they are found existing under extreme conditions.

CHAPTER XIX

N THE COLLECTION, EXAMINATION, AND MOUNTING OF FORAMINIFERA

N taking up the study of Foraminifera it will be ound impossible to confine ourselves either to the ecent or fossil forms, for, in order to learn something f this group of animals, more especially with regard the morphology of the shell, one must be quainted with their occurrence as fossils in the ays, shales, and limestones, as well as in their ore recent condition, whether in deep-sea oozes or shore sands.

On the Collection of Living Foraminifera.—The rface of the ocean is in places teeming with lagic life, especially in the tracts occupied by the rmer currents, as well as the more extensive areas tropical waters; and this plankton fauna contains very large proportion of pelagic Foraminifera, as *lobigerina*, *Orbulina*, *Hastigerina*, *Sphæroidina*, *ullenia*, and *Pulvinulina*. The dead shells of these enera are continually falling through the water to orm the bottom ooze of the ocean floor.

The usual method of collecting the living *lobigerinæ* and other pelagic forms of life is by e use of the ordinary surface tow net (fig. 37).

The net is made of coarse cloth to form a long bag, with an iron hoop of 1 foot to 18 inches in diameter at the mouth. On board the 'Challenger' these tow-nets were dragged either from the ship or from small boats lowered for the purpose; and by this means the beautiful specimens of living *Globigerinæ* and *Orbulinæ*, beset with their long and delicate spines, were collected, figures of which are given in the Report on the Results, vol. ix. plates lxxvii. lxxviii.

Ordinary deep-sea dredges or beam trawls are used at varying depths for collecting the oceanic bottom deposits; for a great many species of Foraminifera habitually live on the ocean floor, where they creep over the surface objects on the mud or sand accumulations, or attach themselves to the seaweeds, stems of hydrozoa, or the long spicules of sponges, such as *Hyalonema*. To make the dredge effective in bringing up the fine oozy material, a piece of fine cloth is tacked on to the inside of the dredge at the bottom.

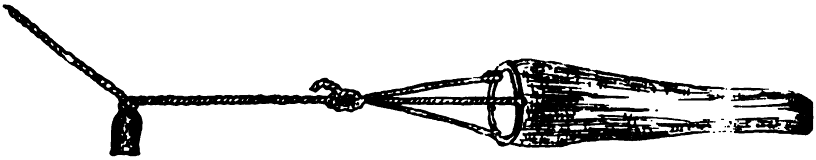


FIG. 37.—THE TOW-NET IN USE (from 'Rep. on Deep-sea Deposits').

In shallow water, Foraminifera in the living condition can be collected from seaweed, and the laminarian zone round the coasts of Britain furnishes us with a good collecting ground. Mr. Halkyard describes the method of procedure as follows:—

'Living Foraminifera may be found by washing in a fine muslin net the small seaweeds and zoophytes growing in low-tide pools. The manner of using the net is as follows: a quantity of weeds, &c., having been gathered, the net is immersed in a pool (care must, however, be taken that the upper edge of the net is kept above water), the weeds being washed one by one inside it; after this is done the contents of the net are turned into a large wide-mouthed bottle full of sea water, for examination on the return home. Of course many other organisms besides Foraminifera will be found in this gathering, such as Ostracoda, Copepoda, and other small crustaceans, which do not make the work any the less interesting.'

If we place the seaweed or the washed-out material into small glass jars or tubes of sea-water, the Foraminifera will travel to the sides and creep about by means of their pseudopodia. They can then be transferred to the stage aquarium for observation by means of dipping tubes. The latter may easily be made by drawing out an ordinary piece of glass tubing in the gas flame, and can be used either straight or curved according to requirements (fig. 38).

The following account of the method of collecting living Foraminifera, especially from a silty area like the Dee estuary, is given by Mr. Siddall, who has had considerable experience in collecting and observing these little organisms. Concerning the Foraminifera obtained he says: 'These have invariably been got from the mud at the bottom of shore pools of greater or less depth. Under the influence of the sunlight the Diatoms and other algæ, which grow in the mud at the bottom of such pools, often rise to the surface in patches. These act as rafts and carry the Rhizopoda up with them. Once up, the outspread pseudopodia enable even the largest and heaviest forms got in our district to float perfectly. I have seen a shore pool at Holywell covered quite thickly with *Polystomella striatopunctata* (the commonest form in the Dee), its reddish-coloured sarcode rendering it easy to distinguish on the surface of the water.'

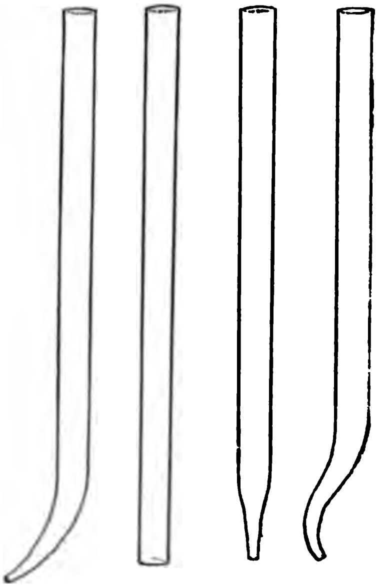


FIG. 38.—VARIOUS FORMS OF DIPPING TUBES.

Regarding the collection of foraminiferal material from the locality in question Mr. Siddall states that 'they may always be got by carefully scraping the surface of the velvety brownish mud at the bottom of pools left by the tide, or by skimming the top of the water, if this mud be found to have risen under the influence of sunlight. The oozy mud may be got rid of by washing through a muslin net, and the residuum put into small bottles filled with sea-water.'

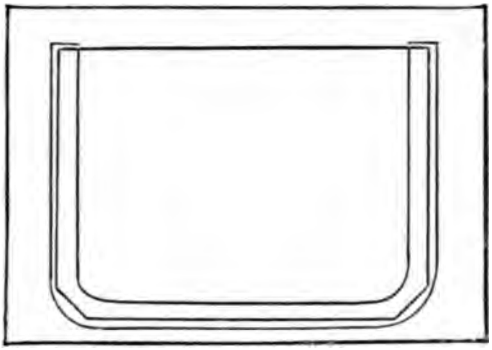


FIG. 39.—STAGE AQUARIUM FOR OBSERVING LIVING FORAMINIFERA.

One of the best contrivances for exhibiting the Foraminifera alive is a glass cell made in the following manner: A thin plate glass slide measuring about 3 in. × 2 in. is taken to form one side of the cell. Next a piece of glass rod, such as that used for stirring purposes, is bent up into a U-shaped form, the sides of which are ground flat with emery and water. This bent rod is cemented to the glass plate by one of the flat surfaces with marine glue or india-rubber cement. Another piece of thin plate glass, of the outer form of the U-shaped rod, is then fastened to the other side, and the cell is complete (fig. 39). Another method is to cement a glass slide through which a hole has been drilled to another slide of the same size, the top of the cell being covered with a thin glass. For a cell of small dimensions the following can be quickly made: A vulcanite ring is split in halves and one of the semicircular pieces cemented to a 3″ × 1″ glass slip. The upper wall of the cell is made by affixing half of a circular cover glass (cut with the point of a writing diamond) with india-rubber cement.

When the object is placed in a cell of this description with sea-water, it may be viewed either as a transparency, in which case, however, the extended pseudopodia are seen with some difficulty, or as an opaque object under a spot lens, or a parabolic reflector. The latter method gives a much better result, for the streaming of the protoplasm along the pseudopodia is well shown in this way. At times the living Foraminifera seem very shy, and refuse to extrude the sarcode through the shell, but if left undisturbed for a short time one is often rewarded by the beautiful phenomenon of the living rhizopod with its extended pseudopodia. The common shallow-water species *Polystomella crispa* makes a very good subject for such observation.

On the Collection and Preparation of Recent and Sub-recent Foraminifera.—The deep-sea oozes are principally obtained by the sounding apparatus and deep-sea dredges. Samples of these deposits we may be fortunate enough to secure from the officers of the various expeditions which have been sent out from time to time, or from the cable-laying companies. These deep-sea oozes and muds require to be cleansed from the finer impalpable deposit of coccoliths by washing through a sieve. In order to retain the smallest Foraminifera the sieve should be covered at the bottom with miller's silk, having about 200 meshes to the inch. The contents of the sieve, after washing away the finest mud, should be slowly and carefully dried, ready for examination with the microscope. If the material to be washed contains many coarse fragments, we must use a sieve of a larger mesh, say 30 or 60 to the inch, to give an intermediate separation.

The soundings taken by an ordinary boat-lead in shallow water are usually mixed with tallow, used for the purpose of arming the hollow end of the sounding lead in securing a sample of the sea-bottom. To clean the material so obtained, the tallow should be melted in a porcelain basin and poured off, and the residue of foraminiferal sand or ooze further cleaned by treatment with benzole.

The shallow-water foraminiferal sands of our coasts may be gathered in the following way: To secure a favourable collecting ground, we must notice the set of the tides and choose a bay which has a considerable stretch of fine sand. The Foraminifera which live amongst the seaweed between tides, becoming detached, float with the incoming tide, and

on its retreat the shells are left behind on the rippl
marked sands, often filling up the furrows and mar
ing the strand with white lines composed of the
minute shells. In proceeding to collect this materi
we may use a large spoon to scrape up the surfa
layer of these streaks, and to fill some muslin ba
with which we should be provided. This materi
will possibly require to be further cleaned a
separated—first, to get rid of the salt from t
water, and secondly, to divide the shells from t
sandy portion, of which latter there will be a varyi
proportion, according to the purity of our foraminife
deposit and the care we bestow upon it in collectin
Sometimes it is found necessary to separate t
lighter Foraminifera from the larger and heavier form
by a process called 'floating.' This is done
gently warming the dried material and then throwi
it upon cold water, when the smaller or lighter a
filled chambered shells, as *Lagena*, *Miliolina*, a
Globigerina, will remain on the surface. These flo
ings can be poured on to a fine muslin sieve, whi
will retain the shells and allow the water to pa
through. The material can then be dried for t
selection and examination of species. In this part
the work the sieves used should have copper sides.
these will not rust nor warp, as iron or wood.
further separation of the sunken or heavier foramii
feral shells may be effected by stirring up the materi
in water and decanting the lighter portion before
can subside.

Another method of separating the lighter foran niferal sand often found useful to the manipulator is that variously known to miners as 'vanning' or 'panning,' in which the sand is put into a shallow dish or pan with water, and a circular motion or dexterous twirl given to it, so as to throw over the edge some of the lighter particles. By this plan, conversely, our 'gold dust' lies in the lighter portion, and this must be collected in a larger vessel placed under that in which the vanning is done.

It occasionally happens that the dead shells of Foraminifera are not so clean as they might be, on account of dried sarcode or other extraneous matter clinging to the surface; or it may be necessary to further empty the shells of the sarcode, shrivelled though it may be, in order the better to observe their internal construction. To clean the shells, therefore, we may resort to the method of boiling the material in a weak solution of caustic potash. After boiling, the shells should be thoroughly washed in clean water and dried slowly, as described before. The foregoing processes apply both to recent and sub-fossil gatherings, for the latter are often in as good a state of preservation as the existing forms, as evidenced by the faunas of estuarine deposits, fossil mud deposits, and raised beaches.

On the Extraction of Fossil Foraminifera from Sedimentary Rocks.—Fossil Foraminifera are obtained from clays and marls by a process of disintegration, the rock being washed down to a sandy and shelly residue, and further cleaned by mechanical or chemical means. In enumerating a few of the more familiar clays and marls which may thus be treated with satisfactory results we may mention the Lias Clays, the Gault Clays and Marls, the London Clay, Bracklesham Clay, Barton Clay, and the Pliocene Clay of St. Erth.

The material chosen to be worked upon for its Foraminifera is broken up into pieces about the size of a walnut, slowly and thoroughly dried in an oven, and dropped, preferably when warm, into a vessel of cold water. The material thus treated should be left to remain undisturbed until the whole of the material has broken up into a fine silty mud, which condition may be tested by raking up a sample with a fork. This precaution has to be taken on account of the tendency of the clay to clot together when touched with the fingers. When the clay is thoroughly disintegrated, forming a more or less fine mud, we may commence to wash away the finest argillaceous portion. The decanting should be done with care, so as to run no risk of pouring off the shells with the mud. The washing is repeated until the water is no longer turbid. For the final cleaning of the residue, which often takes a little extra time if the material is close and refractory, we must pour off as much of the water as possible and vigorously work the vessel with a rotary motion until the residue looks of the consistence of cream. Then we pour on water to fill the vessel, allowing the material to subside before decanting. This should be done repeatedly until no more fine clay can be separated, and the residue looks clean and sandy. Should some clay-flakes still remain unbroken, the material must again be dried and washed.

In the case of shales or indurated muds, such as Kimeridge shale, or the shaly material found as partings between the joints of the Carboniferous limestone, a slightly different treatment may be required, and the material must be broken up mechanically into smaller pieces before washing. Should the work be prosecuted in winter, we may be able to take advantage of a severe frost by exposing the material, just covered with water, to the action of frost, which materially aids its disintegration. But by these means even, it will be found impossible to reduce the whole of the material by washing, and in this case we must have further recourse to sifting after the material is dried, in order to select that portion which will yield the best results when it is sorted. Hard marls may often be broken up by boiling the fragments in a flask with sulphate of soda.

Calcareous sandy rocks, such as the Crag deposits, can only be sifted, in the majority of cases, on account of the friable character of their Foraminifera.

Soft limestones, such as Chalk, can generally be readily broken down by first selecting pieces, not larger than hazel nuts, of the softest material from the particular stratum one wishes to examine, tying them in a strong coarse linen bag, and thoroughly soaking in water. The bag can then be pressed and kneaded, so as to crush the lumps of chalk, and the milky water strained off. This process should be followed so long as the water in which it is steeped is made turbid, and then the residue can be turned out for final cleansing. This may be done by taking a corked bottle, in which we place the chalky sand, and with the merest trace of water; the bottle is then shaken vigorously, so that the particles may be cleaned by a certain amount of friction. If our specimen is well selected, the result will be a sand largely composed of the shells of Foraminifera. Another method, and perhaps a safer one for the shells, is to take a piece of soft chalk and with a tooth-brush briskly rub it under water until a fine sandy residue falls down.

On a larger scale the actions of frost and rain effect what we have here been trying to do; for it is not uncommon to see in chalk districts a fine powdery material lying at the foot of the dip slope, where the rain drains off into runnels, which often consists almost entirely of foraminiferal shells.

In searching for Foraminifera in the harder rocks we must resort to a different method of investigation; for the foraminiferal limestones of the Carboniferous system, and also those of Eocene age, are often extremely hard, and resist all attempts to disintegrate them by ordinary methods such as we have just described. These hard fossiliferous rocks are sliced in the usual way in cutting thin rock-sections, by the lapidary's slitting machine. The slice is then surfaced by grinding on fine emery, and, if it be a limestone, faced on a whet slate. The prepared surface is then cemented to a glass slip by using Canada balsam, and ground down by successive grades of emery powder with water until the required transparency is attained. The slice is then mounted in Canada balsam and covered with a thin glass.

It is the rule to find fossil Foraminifera having their original shells, but in some cases only their partial remains are found, in the form of casts, usually internal. These are formed by the infilling of the chambers with various mineral substances, such as chalcedony, glauconite, marcasite, calcite, phosphatite, chalybite, hæmatite, and limonite.

The hollow flints, containing the fine white powdery substance sometimes known as 'flint meal,' yield casts of Foraminifera in CHALCEDONY generally in abundance. In many cases not only the casts but actual replacements of the tests are found in this substance, as in the meal deposits in the pot stones (paramoudras) in the Chalk of the North of Ireland.

The GLAUCONITE casts of foraminiferal shells are found in extraordinary abundance in certain fossiliferous deposits, as in the Hollybush Sandstone of Shropshire, which is of Cambrian age; and the Neocomian and Aptian glauconitic sandstones of the Isle of Wight. The greensands of the Lower and Upper Greensand formations in the South of England, the Greensand beds of the Gault and the Cambridge Greensand, and also the Upper Cretaceous Hibernian Greensand of the North of Ireland are all largely composed of these glauconite casts, chiefly of Foraminifera. In strata of Tertiary age the basement beds of the London Clay, the glauconitic clays of the Bracklesham series, and the Barton beds also yield glauconitic casts in abundance. Similar glauconitic casts are forming within the shells of Foraminifera at the present day, as, for example, in the greensands and glauconitic muds of the Agulhas Shoal, off the South African coast.

Casts of Foraminifera in iron pyrites, or, more strictly speaking, in Marcasite, are frequent in many clays which are strongly impregnated with sulphides, as the Lias Clay, Gault Clay, and London Clay, and the rapid change from the disulphide into the sulphate is frequently seen in the fracture and ultimate destruction of the shell.

Calcite infillings are often observed in the foraminiferal tests of certain chalk strata, such as that of Southerham, near Lewes, but, owing to the ease with which such casts are broken up, on account of the cleavage in the mineral, they are not often seen in the separated condition. From certain of the Egyptian limestones the writer has described Nummulites and other Foraminifera in which the internal septation is broken down and the whole of the test in some instances occupied by a mould of Calcite.

Phosphatic casts and replacements of Foraminifera are met with abundantly in certain limestone deposits where the strata have been impregnated with phosphoric acid, due to the decomposition of fish remains in many cases, and giving rise to the phosphate of lime or phosphatite. A notable instance of phosphatised Foraminifera is that occurring in the Phosphatic Chalk of Taplow and Twyford. One may easily obtain very beautiful casts of the Foraminifera by dissolving the shells of the phosphatic chalk Foraminifera in weak acetic acid. The residue must be washed and dried with the greatest care, on account of the extreme delicacy of the casts.

Chalybite is sometimes found as an infilling of the Foraminifera *Saccammina* and *Endothyra* in the Carboniferous Limestone; and **Hæmatite** and **Limonite** are occasionally found as casts of Foraminifera in ferruginous limestones which are undergoing decay.

On Examining and Selecting the Shells of Foraminifera. — In discussing the various methods of mounting the Foraminifera we presume that one of the first requisites is a lens or hand magnifier, by which the various larger forms may be discovered and examined. The majority of the species, however, are so small as to make a microscope almost a necessity. Although a triplet hand magnifier will be found useful in going over the coarser siftings, the selection of the smaller Foraminifera must be done with a compound microscope, with objectives having a magnification of at least 30 to 60 diameters. A very convenient microscope stand is that known as the Wale's Binocular, a form which the writer has had in constant use for nearly twenty years, and which is convenient not only on account of the space for deep slides which the hollowed arm affords, but also for the convenient clamping arrangement when the stage of the microscope has to be tilted at high angles for camera lucida or photomicrographic work. The binocular arrangement is also to be recommended for reducing the strain on the eyes of the worker, as both eyes will be used; for the monocular form necessitates work with one eye, and if both eyes are not used alternately the injury done by continued work may be great, especially since the selection of specimens is more often carried on by artificial light and with a comparatively powerful illuminant. It is well to bear in mind, in prosecuting this work, the words of Dr. W. B. Carpenter, who himself devoted forty-five years to microscopical study by artificial light: 'Every microscopist who thus occupies himself, therefore, will do well, as he values his eyes, not merely to adopt the various precautionary measures already specified, but rigorously to keep to the simple rule of not continuing to observe any longer than he can do so without fatigue.' Should the worker be obliged to use a monocular microscope, it would be well if he became used to the method of working with both eyes alternately, so as to divide the strain between them.

The material which contains the foraminiferal shells, and which we wish to sort, is best viewed as an opaque object. A condenser is used to concentrate the rays of light and to illuminate the part immediately in the field of vision; the lamp found to be most useful is perhaps the ordinary one used by microscopists, which is provided with a shade, screening off all but the rays in a direct line with the condenser and object. In regulating the amount of light when working in this way with the microscope it is better to err on the side of too little rather than too much light. In working by ordinary daylight it is preferable to get the rays from a light cloud, direct sunlight being too glaring to the eyes, and there is also a risk of burning the object. A parabolic condenser illuminates the object very well when diffused light is used; and with artificial light this condenser can be used with advantage in conjunction with the bull's-eye condenser.

To facilitate the sorting of material containing foraminiferal shells, it will be found advisable to use a series of sieves of graduated sizes, having an increasing number of meshes to the inch, as, for example, 30, 60, and 120. These sieves can be obtained of chemical apparatus dealers, made with the sieves fitting one upon the other; the material to be sifted is placed in the top, and after a vigorous shake is separated into the various grades ready for examination. It must be remembered that the greatest care should be taken to clean the sieves from one kind of material before using them for another, as all the value of our detailed examination would be lost if we mixed the forms out of different deposits.

In commencing to select the specimens of Foraminifera from the material prepared according to the foregoing methods the sand may be thinly and evenly strewn on a tray, which can be passed over the stage of the microscope. This tray by preference should have a rim, to prevent loss of material over the sides. If the surface of the tray is blackened it forms a good background. Some workers use black ribbed silk to cover the sorti tray, fastened so that the ridges of the silk r horizontally, or from left to right: this will p vent the specimens from rolling when the microsc is inclined for comfort in observation. A use form of tray for sorting purposes may be ma of black vulcanite (ebonite), and rimmed round before; this material, however, loses its black surfa after a year or two, but can then be reblacken with a smooth quick-drying varnish.

Some preliminary sorting may be carried out i mechanical way by taking advantage of the forms the shells. For example, in a medium sifting from ooze, by tilting the tray the *Orbulinæ* will first r down, and on further inclining it the *Globigeri* and *Pulleniæ*. Discoidal forms will remain behi after all the other particles have been made to r off by a gentle persuasive tapping.

On Mounting the Shells of Foraminifera.—I the ordinary purposes of mounting, the opa wooden cell introduced by Dr. Carpenter may adopted (fig. 40). It is a strip of wood 3 inches 1 inch, with a hole bored in the centre. To t wooden slip a thin piece of cardboard is glu which has been previously blackened in the mid with Indian ink, to form a background. Seve slips may be mounted at one time on a long st of cardboard measuring a little more than 3 incl in width, and having a broad black stripe al the centre, and put under pressure: when dry slips can be cut round with a sharp penkni

The thickness of these wooden slips can be made to vary according to the height of the specimens to be mounted in the cells; the shells should in all cases lie below the surface of the slip, to avoid any risk of injury to them. These strips of wood may be cheaply prepared from the wood of cigar boxes, by cutting through both surfaces with a marking gauge. Should a large number of the slips be required, it will be easier to procure a block of wood (preferably mahogany) measuring 3 inches by 1 inch, and of any required length, bored through from end to end and sliced up by a circular saw according to the needed thickness. The holes in these slips may be made to vary according to the area which the shells will occupy, convenient sizes being $\frac{13}{16}$ inch, $\frac{1}{2}$ inch, and $\frac{1}{4}$ inch diameters.

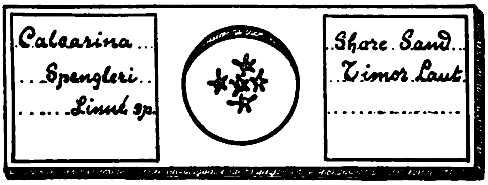


Fig. 40.—Method of Mounting Foraminifera in Dry Cells.

There is another form of mount which is of great convenience to the worker on account of its compactness.[1] It is made of a piece of thick cardboard measuring 3 inches by 1 inch or wider, and has a rectangular piece punched out of the middle; to thi is glued at the back a form stuck on thin cardboar on which are photographed or lithographed a numbe of divisions, each having a numeral placed in th corner in rotation. The mount is covered fo security by a case made from a 3 by 1 inch glas slip, a piece of thin cardboard of the same size, an a piece of tinted writing paper cut to enclose th whole. The card is glued to the centre of the pape and lunettes punched out at the ends for the insertion of the finger-tip when removing the sheath. The tray is placed on the top of the card and covered with the slip, and the edges of the paper turned up and fastened over the slip (fig. 41). These mounts are very convenient for the storage space they afford for the little specimens, and when covered with the case they are quite dust-tight. They may be made of various widths, keeping to the 3-inch length as convenient, and to contain 10, 30, 50, or even 100

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[1] The original form was devised by Messrs. William Swanston and Joseph Wright.

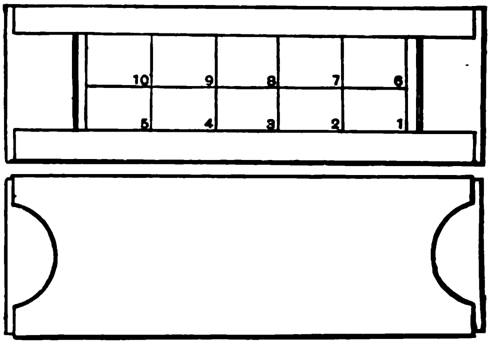

Fig. 41.—Method of Mounting a Series of Foraminifera on One Slide.

spaces as required. If the form is photographed, say, from a diagram drawn up in Chinese white, the lines in the positive will of course also appear white. The forms can then be printed on ordinary bromide paper, which will give a good dense black. The general title and name of the formation to which the specimens on the mount belong may be written on the white card at the ends of the mount, and a number given which will refer to a list of the species it contains, kept in an index register elsewhere.

To attach the shells of Foraminifera to the mounts, gum arabic is most frequently used. A few drops of glycerine should be added to an ounce of the gum. This will prevent the gum from becoming brittle and spoiling the shells by its fracture, especially when exposed to a very dry atmosphere. Better than gum arabic, however, is gum tragacanth, for when this dries it is practically invisible on the mount. To prepare it the gum should be steeped in water until it swells, when it should be dissolved in a little warm water until it is of the consistency of a thin jelly.

In mounting the minuter Foraminifera the surface of the mount should be brushed over with a film of gum, and when the object is transferred to it a slight breathing close to the surface will deposit sufficient moisture to cause the shell to adhere. Larger Foraminifera may be cemented one by one by placing little spots of gum where they are to be affixed.

The best brushes for the purpose of selecting and mounting the little tests are the finest red sables, which should have a fine and fairly flexible point.

An ingenious mount for showing opaque objects, such as Foraminifera, in various positions by a turning arrangement has lately been described by J. J. Harvey in the following words: 'One of the many objections to the present system of mounting opaque objects is that it is necessary to permanently hide one side of the specimen, and in the case of aberrant or rare forms this may greatly lessen the value and interest of the slide. The method here advocated allows of the revolution of the object under the microscope, and permits of its examination with as much ease as a hand specimen. It is at the same time as permanent and as compact as the older system. Another important advantage is the differential lighting which this rotation brings into play, and which the inventor has found of special service in the study of the Foraminifera for which this method was originally designed. The slides used are the wooden slips recommended for this class of objects by Carpenter and others. The specimen is attached by means of a suitable medium to the end of a needle (fig. 42 B) which has been thrust through the centre of a plug of indiarubber cord C. This is laid, with the specimen projecting into the central cell D, in a shallow longitudinal groove A cut just deep enough to enable the specimen to revolve without touching the cover-glass, a hole also having been cut for the reception of the rubber plug. The projection of this plug above the surface allows the whole arrangement to revolve by the mere movement of the finger. When the cover glass has been placed in position the whole can be finished off with paper in the usual way. A neater appearance is obtained by mounting two specimens in each slip, one on either side of the cell.'

We will now transfer our attention to the methods for mounting Foraminifera as more or less transparent objects in media. After cleaning the material as far as possible, and by the use of liquor potassæ, the shells may be immersed in a thin solution of Canada balsam dissolved in turpentine, chloroform, ether, or benzole; this will saturate the tests and expel the air from the chambers. It is by some thought to be expedient to place the vessel containing the shells under an air-pump to complete the process of filling the internal chambers and extracting the air, but this does not in the majority of cases seem necessary. The tests of the Foraminifera can, after the lapse of a few hours' immersion, be mounted in the ordinary way in Canada balsam, using a gentle heat and covering with a thin glass.

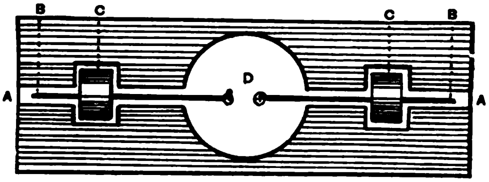

FIG. 42.—HARVEY'S METHOD OF MOUNTING OPAQUE OBJECTS.

It is sometimes desired to arrange a group (Foraminifera, or a series, upon a slide before mountin in balsam. This can be effected by washing the su face of the slide with a thin layer of gum ; the object may then be placed in position, or arranged with th aid of a moistened brush or a needle mounted in handle. The specimens can then be covered wit Canada balsam and mounted in the usual way.

On Preparing Thin Sections of the Tests (Foraminifera.—The internal structure of the foram niferal test is revealed by means of thin sections cu in various and definite directions. Sometimes onl one half-section is required, and if the specime be large, like a Nummulite or an *Orbitoides*, th object may be held in a cork slightly hollowed ε the end, into which the specimen is pressed, an rubbed on a snakestone or Water-of-Ayr stone wit water until one half of the specimen is entire removed by grinding.

In the same way a polished specimen of a foram niferal limestone will show the included tests Foraminifera cut in various directions, and whe this surface is examined with a lens a great de may be learned about the internal structure of suc fossils.

When a thin section of a shell measuring n more than $\frac{1}{60}$ inch in diameter, or even smaller, ha to be cut through the median plane, then the coars methods of cutting and polishing must be re linquished for the more delicate methods of Wallicl Schlumberger, and others.

In 1861 Dr. Wallich described the following very ingenious way of obtaining slices of minute objects, as the shells of the Foraminifera; the chief point in his method being the plan of turning a number of specimens over together, so as to expose the alternate sides for grinding. The specimens are cemented with Canada balsam in the first instance to a thin film of mica, which is then attached to a glass slide by the same means; when they have been ground down as far as may be desired (upon the snakestone) the slide is gradually heated, just sufficiently to allow of the detachment of the mica-film and the specimens it carries, and a thin slide with a clean layer of hardened balsam having been prepared, the mica-film is transferred to it with the ground surface downwards. When its adhesion is complete the grinding may be proceeded with, and as the mica-film will yield to the stone without the least difficulty, the specimen, now reversed in position, may be reduced to the requisite thinness.

In the preparations of sections of Foraminifera by this method it is necessary, in the case of shells with inflated chambers, to take care that the *whole test* is permeated with the fluid Canada balsam, and in order to do this the shells must be placed in the balsam before the latter is quite tough, so that during the few seconds of prolonged heating which will be required to bring the cement up to the proper degree of toughness, the balsam will have the opportunity of penetrating to the innermost recesses of the shell. Instead of grinding off the mica-film, as

Wallich describes, it may be easily split from the balsam when the latter is cold; and, moreover, this will provide a test as to the proper toughness of the balsam, for it should shell off with ease when a knife point is inserted under one corner, and it should at the same time be noticed that the balsam does not powder under the knife point, for in that case it will be too brittle to grind with safety to the shells.

Some of the most interesting discoveries during past years on the morphology of the foraminiferal shell have been made by M. Schlumberger, and he has shown by means of his superior skill in preparing thin sections of Foraminifera, chiefly of the Miliolidæ, that the same species presents two entirely different aspects with regard to their inner plans of growth, and to which reference has already been made on the subject of dimorphism. The following is a translation of Schlumberger's description of his method of preparing these sections, which is given by Heron-Allen in his useful and suggestive 'Prolegomena towards the Study of the Foraminifera:'—

'The apparatus necessary is very slight, and the whole operation may be performed within the most restricted space. A bottle of chloroform, one of Canada balsam, a few stoppered tubes, two or three fine brushes, a scalpel, a stone such as is used for grinding razors, a piece of pumice stone, and a spirit lamp are all that is necessary in addition to the ordinary accessories of a good microscope. One side of the piece of pumice stone must be kept always very plane by means of a fine file.

'Suppose that we desire to obtain a section of a *Biloculina.* The first object to be attained is the filling of all its chambers, to the very centre or primordial chamber, with a medium sufficiently resisting to prevent the shell being crushed by the action of the rubbing stone. To effect this the *Biloculina* must be dropped into a stoppered tube with a little chloroform, upon which at first it will most probably float, but the fluid penetrating little by little into the inner chamber will drive out the air, and the test will sink to the bottom of the tube. After letting it remain there for a while it is picked out and set in a drop of Canada balsam, placed upon the centre of a cover slip. The chloroform being a rapid and perfect solvent of Canada balsam, the latter will soon penetrate to the inmost chambers; but it is desirable, if one is not pressed for time, to wait a day or two before continuing the operation, in order that the chloroform may disappear from the chambers by evaporation as completely as possible; this prevents the inconvenient presence of bubbles of air in the subsequent stages of the operation.

'When one judges that the balsam has sufficiently penetrated all the chambers of the test, one warms the cover glass over the spirit lamp to drive off the volatile constituents of the resin, and before the drop of balsam containing the test has become cold and hard the test is placed in the position required for making the section by means of a hot needle or stiff brush; vertically if one wants a transverse, or horizontally if one wants a vertical, section.

'At this point it is necessary to be sure whether the balsam is of the right consistency, i.e. neither too hard nor too soft; in the former case it will splinter away and the test be torn from its position, and in the latter the rubbing action of the stone will crush the walls of the chambers. If, however, you always use the same balsam and the same method of heating it, you will soon be able to bring it always to the required condition, but to make sure it is advisable to take up a tiny drop of the balsam whilst still soft with a needle and let it cool, and if it crumbles into fragments when pressed upon the finger-nail you can safely proceed with the operation.

'Place the cover slip upon a flat surface, place a moistened plane of the grinding-stone (or hone) upon the test, and commence rubbing it softly with a circular movement of the hone. The greatest care must be taken to keep the hone absolutely parallel to the plane of the section you desire to make, as the test wears down and the hone rubs closer to the cover slip. One cannot see the progress of the operation with the naked eye, but the section in progress must be *constantly* examined under the microscope, washing away the muddy detritus of the test with a wet brush before each examination. Almost immediately the internal chambers make their appearance, outlined in white on the yellowish matrix formed by the balsam, and one continues until one judges that one is almost down to the primordial, or centre, chamber. Then dry the section and re-warm the balsam, and with the needle (under a lens or low-power objective) turn the test over, in the balsam, on to its now flattened surface; by transmitted light under the microscope you can see in the centre of the section the little round primordial chamber, and by focussing *through* it you can judge how much must be rubbed away on either side to reach the centre of this chamber, at which point the section is to be taken.

'When the test is worn down to this central point on either side the section is once more turned over, and, with a fine scalpel, the superfluous balsam is scraped away round the section, after which the rubbing down is carried to the finest possible degree. This turning over must be accomplished with the greatest care, for if the warmed balsam is too "tacky" at this point the central chambers may be carried away, or the outer ones (especially in the case of the *Miliolinæ*) may disintegrate. To obviate this the balsam must be *thoroughly* fluidified, when the section may be turned over by pushing one or two hairs of a fine brush underneath it. In some species the arrangement of the chambers is such that, when the rubbing has been carried down to the central chamber, the centre of the section finds itself isolated from the periphery, and *then* the turning must be done in the cold or hardened state; that is to say, the whole mass of balsam, with the embedded section, must be dexterously split off the glass with the scalpel, and not warmed again until it has been turned over upon a fresh area of the cover slip.

'To avoid importing confusion into the above exposition, I have omitted to refer to certain precautions that must be taken. It is obvious that in rubbing down the test in the balsam, especially if the test contain siliceous granules, the hone will itself be worn away, and however slight this wear may be, unless it is corrected, one would in time be making a convex surface, the result of which would be that, when the section is turned over, the greater resistance of the periphery would cause it to be worn away before the central chamber was reached. It is here that the pumice-stone comes into use, and by its continual use during the operation the rubbing surface of the hone is kept quite plane. One small difficulty sometimes attends the use of the pumice-stone. The glassy detritus of the latter adhering to the hone, whilst it assists the operation of rubbing down, has a tendency to get into and clog the section, introducing itself either into the chambers or into any minute air-bubbles that may be present. This glassy mud will soil and confuse the section, but it may be got rid of by means of a strong jet of water from a tap or wash-bottle directed upon the section through a glass tube drawn out to a fine point. When the section is thus cleared, the little spaces left by the process may be filled up with a fine brush dipped in a solution of balsam in chloroform, after which the section is again warmed and allowed to cool. If recourse to the tap or wash-bottle is impracticable these fragments of pumice may be got rid of by covering the section with a little of the balsam solution and heating it, when the ebullition of the medium will bring the particles to the surface with the air-bubbles, when they may be removed, as they form, with a fine brush.

'Careful observance of these directions will ensure success, after perhaps a failure or two; the most annoying casualty being that often, at the last moment, a too vigorous rub may wipe the whole section out of existence, in which case the only thing you can do is to begin again upon another specimen.'

The above excellent description is given in full, since, if these minute instructions are carefully followed, there is more chance of success.

The following method for hardening and slicing friable deposits and loose sands has been devised by F. G. Pearcey, and used with much success in the 'Challenger' Office :—

The dried deposit or sand is placed in a small pill box, upon which is poured a solution of mastic dissolved in benzole. The mass is hardened by slowly heating in a hot-water oven, and when cold the piece is sliced into layers about $\frac{1}{16}$ inch thick or more. These slices are rubbed down and polished upon the snakestone, after being cemented to a thin glass, which in turn is fastened to a glass slip. When one surface has been sufficiently prepared, the cover glass is removed by a gentle warming, and then cemented in the reverse position with Canada balsam to a glass slide. The cover glass can then be ground away or carefully flaked off, and the rubbing down proceeded with until thin enough; it is then mounted in the usual way with Canada balsam and a cover glass, great care being taken to avoid displacing the prepared section by too much pressure.

It will now be convenient to describe the method of making sections of chalk.

The above plan will also answer equally well for this, but the following is the usual way of procedure:—

The chalk selected for the section should, if possible, be cut into a slice with fairly parallel sides, and having a thickness of $\frac{1}{8}$ inch or so. This slicing is not absolutely necessary, but it ensures the better permeation of the rock; whereas if a chip is used it will take a longer period for the medium to penetrate to the plane through which the section is to be made. The slice or chip is carefully warmed, to drive out any moist air which may lurk in the recesses of the specimen; and at the same time we should have in preparation an evaporating basin, of about $2\frac{1}{2}$ inches in diameter, half filled with Canada balsam, and resting on a tripod and piece of wire gauze, placed over the flame of a spirit lamp. When the balsam has been heated to the condition of being nearly tough when cold, tested by drawing out a thread on the point of the forceps, the piece of chalk may be dropped in and allowed to absorb the balsam freely. If a few flakes of shellac be added to the balsam it will render the chalk more coherent in the process of grinding. After the lapse of a little time, and when the bubbles of air cease to be given off, the flame should be withdrawn, and the specimen allowed to partially cool in the balsam. This is done in order that, during the contraction of the balsam in the rock, the interstitial spaces may be kept completely filled with the medium; if this is not carefully attended to, the chalk will grind up readily into a mud when we endeavour to produce a surface upon it, and the result will be a hole in that particular part of the section. As soon as the balsam begins to harden, our specimen must be withdrawn and left to cool down. The superficial balsam is then scraped away with a penknife, and a surface produced upon it with a snakestone and water. When one face is sufficiently smooth, presenting an even balsam-filled surface, it should be carefully dried and cemented with balsam to a glass slip. The bulk of the chalk may then be ground away on medium-grain emery, and the finishing proceeded with as in the preparation of the preliminary surface, by rubbing down on a perfectly plane snakestone. As soon as the section is nearing completion little spots of light may appear through the section, showing the presence of organisms. This thinning down should be continued until the matrix is also fairly translucent, and then it may be mounted with fluid balsam, using a very moderate heat to harden the medium. It is often of great convenience to make a section of chalk before proceeding to wash down a quantity for the extraction of the Foraminifera, for by this means we are enabled to see whether the specimen is worth the trouble of disintegration.

To prepare the Sarcode Bodies of Foraminifera.—In order to examine the sarcode for structures such as the nucleus, the gemmules or zoöspores, and so forth, it is essential to remove or decalcify the shell. In order to do this successfully the body of the foraminifer, which is jellylike in consistence, must be hardened; and this process should go on side by side with the dissolution of the shell. The best reagent for doing this is undoubtedly that known as Perenyi's Fluid. It consists of nitric acid, 10 per cent. sol., 4 vols.; alcohol (absolute), 3 vols.; chromic acid, 5 per cent., 3 vols.

If we are able to obtain the living animals by dredging, the material should be bottled, until required, in weak spirit, or, what is perhaps better, a weak solution of formalin. On selecting our specimens for decalcification they may be placed on a thin cover glass in the solution mentioned above, contained preferably in a glass box with a lid, a covered watch-glass, or other convenient vessel, and left undisturbed until the solution of the shell is effected. Should the organism require to be stained, the cover glass with the specimen may be gently lifted by means of a section-lifter, and transferred to a fresh vessel containing water; and afterwards to a weak solution of picro-carmine. After the lapse of half an hour it may be transferred to methylated spirit. If the specimen be washed in water after staining, the picric acid is removed, otherwise it acts as a yellow stain to the protoplasm, whilst the nucleus and nutritive particles take up the carmine. The cover glass is next placed beside a slip and gently warmed in a water bath, at the same time introducing a drop of fluid glycerine jelly beside the object. This will presently run in, and a minute piece of the jelly having been melted upon the glass slip, the cover glass can be turned over on to the slide. Extreme care must be taken during this operation, so as not to displace the fragile object. When cold the superfluous jelly may be removed with a damp cloth and the mount surrounded with a ring of gum arabic, and finally with varnish.

Apparatus used in drawing the Foraminifera.—It is hardly necessary to give many details on this branch of the subject in a book of small pretensions, such as this; especially since much valuable information is always available in the well-known works of Carpenter on 'The Microscope' and Dr. Beale on 'How to work with the Microscope,' not forgetting several of a similarly useful character lately published.

The camera lucida is to some workers a very indispensable piece of apparatus; the two best known forms being Wollaston's prism and Beale's neutral tint reflector. Many persons, however, have not found these accessories necessary, but trust rather to drawing and measuring alternately, so as to ensure accuracy. It is, however, better to employ a form of camera lucida in getting the outlines of the objects, when the detailed filling in may be done with more freedom.

Another extremely useful piece of apparatus which the writer has often employed in making drawings is Beck's revolving disc, which carries a needle, to the point of which a specimen may be affixed; and by means of a universal movement of the apparatus, this can be turned in all directions.

CHAPTER XX

BIBLIOGRAPHICAL LISTS, TO FACILITATE REFERENCE TO THE PRINCIPAL LINES OF RESEARCH; COMPRISING THE MORE IMPORTANT WORKS ON FORAMINIFERA, ESPECIALLY THOSE OF RECENT DATE

THE selection given below is necessarily incomplete, but is sufficient to enable the student of this subject to gain further information by references to be found in the works themselves.

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